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Heat-treatment of Molybdenum High-speed Steels

Substitution is a natural expedient when material shortages develop, and in many cases a different technique is necessary in order that the substituted material will give results as near as possible to those obtained from the material it substitutes. To some extent molybdenum is being substituted for tungsten in high-speed steels, and three reports dealing with heat-treatment technique and furnaces suitable for molybdenum high-speed steels, have been prepared by a special committee of the Office of Production Management of the United States, the main recommendations from which are given in this article.*

MOLYBDENUM high-speed steels have a tendency to develop a soft surface when heated to the hardening temperatures. Because of this tendency it is necessary and important to exercise certain well-established precautions to protect the surface of these steels. Where hardening equipment is available in which decarburisation can be controlled, however, there is no particular problem involved in using these steels to replace tungsten high-speed steels. When the use of proper equipment is not available greater care is necessary and special precautions given will be helpful.

The composition of molybdenum high-speed steels as given in Table I include only those which are widely used and established for general commercial tool applications. A number of additional compositions are in use for special purposes, but since these involve special heat-treatment to handle properly, they are excluded from the practice which is applied to the steels given.

TABLE I.
COMPOSITIONS FOR MOLYBDENUM HIGH-SPEED STEELS.

	Type I. Molybdenum-tungsten.		Type II. Molybdenum-vanadium.	Type III. Tungsten-molybdenum.
	a	b*		
C	0·70–0·85	0·76–0·82	0·70–0·90	0·75–0·90
W	1·25–2·00	1·60–2·30	—	5·00–6·00
Cr	3·00–5·00	3·70–4·20	3·00–5·00	3·50–5·00
V	0·90–1·50	1·05–1·35	1·50–2·25	1·45–1·75
Mo	8·00–9·00	8·00–9·00	7·50–9·50	3·50–5·50
Co	See footnote	4·50–5·50	See footnote	See footnote

* Cobalt may be used in any of these steels in varying amounts up to 9·00%, and the vanadium may be as high as 2·25%. When cobalt is used in Type III, this steel becomes susceptible to decarburisation. As an illustration of the use of cobalt Type 1b is included.

For those who are not skilled in handling molybdenum high-speed steels, and who do not have decarburisation under good control, it is recommended that at present they adopt the following procedure :—

Use the required substitution of molybdenum high-speed steels, selecting the type that will produce the best results and give the least trouble in working. The smaller tools are heat-treated by shorter cycles and thus the general hazards are less.

Proceed on the basis that steels of Type III decarburise less than steels of Type I and II. In most cases steels of Type III can be treated without surface protection in the same equipment used for tungsten high-speed steels.

Consult with the firms from whom you purchase your high-speed steels for their advice in the light of your particular problem. Take steps to obtain modern, efficient hardening equipment on the premise that, regardless of the kind of high-speed steel being hardened, proper hardening promotes better tool life, which is a big step in conservation.

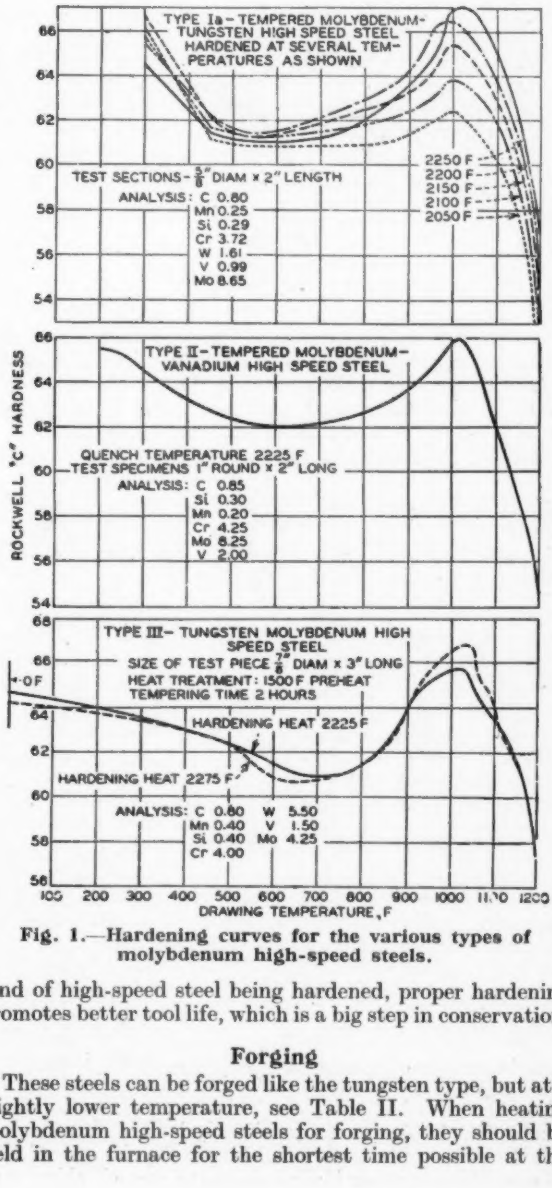

Fig. 1.—Hardening curves for the various types of molybdenum high-speed steels.

Forging

These steels can be forged like the tungsten type, but at a slightly lower temperature, see Table II. When heating molybdenum high-speed steels for forging, they should be held in the furnace for the shortest time possible at the

* *Mech. Eng.*, 1941, **63**, pp. 703–6.

forging temperature. Like all types of high-speed steel, large pieces should be preheated to 675°–820° C. before heating to the forging temperature.

Slightly oxidising atmospheres are preferred when no protective coating is used. No protection is necessary for ordinary sized forgings unless long heating cycles are involved. Borax is a very effective coating, but has the disadvantage of making the surface of the steel very slippery at the forging temperature and the operator should take precautions. To minimise the fluxing action on the furnace refractories, an excess of borax should be avoided.

TABLE II.
HEAT-TREATMENT OF MOLYBDENUM HIGH-SPEED STEELS.[1]

	Type I. Molybdenum-Tungsten *a* and *b*, ° C.	Type II. Molybdenum-Vanadium, ° C.	Type III. Tungsten-Molybdenum, ° C.
Forging	1,010–1,100	1,010–1,100	1,040–1,120
Not below	860	860	860
Annealing	790– 840	790– 840	790– 840
Strain relief	620– 730	620– 730	620– 730
Pre-heating	675– 815	675– 815	675– 845
Hardening[3]	1,175–1,230[2]	11,75–1,230	1,190–1,245
Salt	1,175–1,220	1,175–1,220	1,175–1,230
Tempering	510– 600	510– 600	510– 600

1 Hardening curves of the various types are given in Fig. 1.
2 Under similar conditions, Type *b* requires a slightly higher hardening heat than Type *a*.
3 The higher side of the hardening range should be used for the large sections and the lower side for the small sections.

After forging it is desirable to cool slowly to about 620° C. to avoid cracking from forging strains. This can be accomplished by furnace cooling or burying in lime, mica, or dry ashes, or the like. Tools that have been forged should be machined or rough-ground, after annealing, to remove possible surface defects and to reduce the amount of grinding after hardening.

Annealing

Like tungsten high-speed steels, these steels should be annealed after forging and before hardening, or when rehardening is required. Box annealing is always preferable. When annealing partially finished tools, and generally when surface protection is of prime importance, it is recommended that cast-iron chips or other mild source of carbon be used for packing material.

Heat slowly and uniformly to the temperature given in Table II, soak thoroughly, and then cool slowly in the furnace. The steel should not be taken from the furnace until it is below 550° C.

After machining and before hardening it may be necessary to relieve harmful machining strains by annealing at 620°–730° C.

Hardening

The general method of hardening molybdenum high-speed steels resembles that followed with 18–4–1, but the hardening temperatures (Table II) are lower and more precautions must be taken to avoid decarburisation, especially on tools made from Type I or II when the surface is not ground after hardening. Salt baths and atmosphere-controlled furnaces represent an excellent type of equipment for hardening molybdenum high-speed steel. The use of coke fires or the blacksmith forge is not recommended for hardening any high-speed steel, but if this type of equipment is all that is available, Type III may be so treated if an excess of air is avoided. However, simple surface protection in such equipment is safer practice even in the case of tungsten high-speed steels.

The usual method is to preheat uniformly in a separate furnace to 675°–845° C. and transfer to a high-heat furnace maintained at the hardening temperatures (see Table II).

When heated in open fire or in furnaces without atmosphere control, these steels do not sweat like 18–4–1. Consequently, the proper time in the high-heat chamber is a matter of experience. This time approximates that used with 18–4–1, although slightly longer when the lower part of the hardening range is used. Much can be learned by hardening preliminary test-pieces and checking up on the hardness fracture and structure. It is difficult to state exact heating time, as this is affected by temperature, type of furnace, size and shape, and furnace atmosphere.

Rate of heat transfer is most rapid in salt baths, and slowest in controlled atmosphere furnaces with high carbon-monoxide content.

Quenching

Quench the tool in oil, air, or molten bath. To reduce the possibility of breakage and undue distortion in intricately shaped tools, it is advisable to quench in a molten bath at approximately 1,100° F. The tool may be quenched in oil and removed while still red or at approximately 1,100° F. The tool is then cooled in air to room temperature and tempered immediately to avoid cracking.

Straightening

When straightening is necessary, it should be done after quenching and before cooling to room temperature prior to tempering.

Tempering

Reheat slowly and uniformly to 510°–600° C. For general work 570° C. is most common. Hold at temperature at least 1 hour. Two hours is a better safe minimum, and 4 hours is maximum. The time and temperature depend upon the hardness and toughness required. Where tools are subjected to more or less shock, multiple temperings are suggested.

Coatings

Borax may be applied by lightly sprinkling over the steel when heated to a relatively low temperature (650°–750° C.). Small tools heated in the foregoing manner may be rolled in a box of borax. Another method more suitable for finished tools is to apply the borax or boric acid in the form of a supersaturated water solution. In such cases the tools are immersed in the solution at 80°–100° C., or it may be applied with a brush or spray. Pieces so heated are treated as usual, care being taken in handling to ensure good adherence.

Many special proprietary protective coatings or paints are available, and when properly applied have been found extremely useful. They do not fuse or run at the temperature used, and therefore do not affect the furnace-hearth. When applying these coatings, it is necessary to have a surface free from scale or grease to ensure good adherence. They may be brushed or sprayed on and usually one thin coat is sufficient. After hardening and tempering the coating can be easily removed by light blasting with sand or steel shot. When tools are lightly ground, these coatings come off immediately.

Special Suggestions

As in the case of tungsten high-speed steels, tools with sharp corners, variable cross-sections, or very large sizes should not be given too drastic a quench in oil. It is better to remove the tool from the oil when cooled to or just below a red heat and allow it to cool in the air. Equalising in lead or molten salt at about 600° C. and then cooling in still air is good practice.

Single-point cutting tools, in general, should be hardened at the upper end of the temperature range as given in Table II. Slight grain coarsening on such tools is not objectionable when they are properly supported in service and not subjected to chattering. When such tools are used for intermittent cutting, however, it is better to use the middle of the temperature range. All other cutting tools, such as drills, countersinks, taps, milling cutters, reamers, broaches, and form tools should be hardened in the middle of the range.

Certain applications requiring a maximum toughness (to resist shocks) will require the lower end of the hardening range. Examples are slender taps, cold punches, blanking and trimming dies.

The molybdenum high-speed steels may be pack-hardened following the same practice as used with tungsten high-speed steels, but keeping on the lower side of the

hardening range (approximately 1,000° C.). They will take all the special surface treatments, including nitriding by immersion in molten cyanide, that are applied to tungsten high-speed steels for certain applications.

When borax and boric acid are used in a furnace with a silicon-carbide bottom, it is necessary to use a metal pan, preferably of stainless iron, to prevent the borax from fusing with the silicon-carbide. Such fusion produces a glass-like insoluble coating on the tool which is impossible to remove without damage to the cutting edge.

Salt Bath Furnaces

The electric salt-bath method for hardening, when properly controlled, eliminates decarburisation and is satisfactory for all types of molybdenum high-speed steels. In general, immersed-electrode furnaces are being used where there is sufficient production to keep furnaces operating at a reasonable capacity. The immersed electrodes produce a positive circulation of the bath, due to the internal stirring action caused by the electrical flow between the electrodes. This stirring action increases the speed of heating and eliminates local overheating, thus aiding close temperature control which is always advantageous. A properly selected and maintained salt bath prevents scaling or oxidation of the work, and when properly controlled also prevents surface decarburisation.

For heavy production and constant use three immersed electrode salt-bath furnaces are recommended: one for preheating, the second for the hardening temperature, and the third for the quench operation. Under extremely heavy production conditions, or when large or intricate sections are involved, two preheats are an advantage, the first operating at 600°–700° C. and the second 800°–875° C. For medium or light production necessitating intermittent operation, a three-pot unit comprising a gas- or oil-fired salt-bath preheat furnace; an immersed-electrode salt-bath high-heat furnace; and a gas- or oil-fired salt-bath quench furnace, is recommended.

The procedure recommended when using salt-bath furnaces is as follows:—

1. Clean work free from scale, rust, oil, grease, and moisture. Use either solvent degreaser or suitable alkaline cleaner, followed by a clean hot-water rinse, and thorough drying. Every precaution must be taken to prevent moisture on tools going into the salt, as wet tools may cause a steam explosion, burning the operator.

2. Immerse in preheat salt bath, temperature 1,500°–1,550° F. Allow sufficient time for work to reach temperature of bath.

3. Transfer to high-heat salt bath, temperature 2,150°–2,250° F. Allow sufficient time for work to reach temperature of bath, plus proper soaking time at temperature. (See the heat-treatment practice by the O.P.M. Committee on the Heat-treatment of Molybdenum High-speed Steels.)

4. Transfer to quench bath, temperature 1,100°–1,200° F. Allow sufficient time to cool to bath temperature. Two to five minutes will suffice, depending upon size. Remove from salt bath and cool in air or oil. Quenching in oil is not recommended for work of intricate design or work where distortion is apt to occur.

5. After work has cooled to room temperature, wash off all adhering salts in a hot alkaline cleaner. If the work is to be tempered in a furnace (air atmosphere), the work should be shot- or sand-blasted or cleaned by other methods, to ensure removal of all adhering salts. If this is not done, the salt will attack the work during the tempering. If a salt bath is used for tempering, the work need only be cleaned in a hot alkaline solution or hot water.

6. For tempering, see the practice recommended previously.

Controlled Atmosphere Furnaces

In addition to the application of protective coatings when conventional type furnaces are used for the heat-treatment of molybdenum high-speed steels, and also the use of high-temperature salt baths, atmosphere controlled furnaces satisfy the requirements for surface protection against attack. These furnaces are available in both electric and fuel-fired types, where the atmosphere is independent of the source of heat. This permits control of the atmosphere in contact with the work to be treated.

In the selection of atmosphere-controlled furnaces whether for preheating or for the higher hardening temperatures, it is recommended that the purchaser should secure a guarantee that the furnace selected will satisfactorily harden molybdenum high-speed steels for his particular needs without the use of surface-coating materials. Complete operating information should be provided when the furnaces are installed, so that they can be operated under conditions which will give the best results.

Some Creep Properties of Chromium-Nickel-Molybdenum Steels

In the March issue of Metallurgia for 1940, a summary was given of an investigation[1] dealing with the creep properties of 5% chromium, 1–1·5% molybdenum steel. This work was based on a co-operative research carried out by three companies in the United States. Since then a further extensive investigation has been undertaken by one of the associated companies on the creep and other properties of a 16% chromium, 13% nickel, 3% molybdenum steel, and the results obtained are discussed by H. D. Newell.[2]

The addition of about 3% molybdenum to a steel containing 18% chromium, 9% nickel with a maxima of 0·75% silicon, 0·60% manganese, 0·07% carbon, and 0·03% each of phosphorus and sulphur produces delta ferrite in the structure. Where the carbon is held at the low level necessary for corrosion resistance, a molybdenum addition with its strong ferritising effect throws the structure outside the austenitic range. Material of this duplex structure does not work hot well, rupture taking place through the weaker ferrite areas, rendering the material particularly unsuitable for piercing into seamless tubing.

1 *Metals and Alloys.* 1939, vol. 10, No. 11, pp. 342-345.
2 *Metals and Alloys.* 1941, vol. 14, No. 2, pp. 173-181.

An alloy with a composition nearer to 16% chromium, 13% nickel, 3% molybdenum, has a full austenitic structure. It has also a good resistance to corrosion, and very useful high-temperature properties, and has been found very suitable for tubes for high temperature oil-cracking operations and certain polymerization and alkylation processes. It resists oxidation under continuous service up to at least 925° C. and at ordinary temperatures.

In developing the alloy for tubing for use at high temperatures, it was found necessary to evaluate the effect of variations in carbon and manganese on the behaviour of the alloy in hot piercing at 1,095° to 1,205° C., in the range of service temperatures up to 925° C., and at ordinary temperatures. Initial experiments were carried out on rolled specimens of a laboratory-prepared steel containing 0·11% carbon, 0·34% silicon, 0·51% manganese, 16·5% chromium, 13·36% nickel, and 2·73% molybdenum. These specimens were first subjected to creep tests and were then tested in tension and in impact at room temperature on sub-size test-bars. From these experiments, the material was shown to have very good creep resistance and good toughness after creep.

Three samples of commercial steels with varying carbon

and manganese contents, cast in 12 in. by 12 in. ingot, hot-rolled to 1 in. round bars, and air-cooled from 1,080° C. were then tested. The composition and properties of these steels at atmospheric temperature are given in Table I. Steel A was also tested after an air cooling from 830° C.

TABLE I.

—	A.		B.	C.
	%		%	%
C	0·074		0·096	0·11
Si	0·35		0·45	0·26
Mn	0·36		1·32	1·00
Cr	16·79		16·74	17·03
Ni	13·84		14·16	14·60
Mo	2·66		2·65	2·56
Treatment.	1,080° C./air	830° C./air	1,080° C./air	1,080° C./air
Prop. Limit, tons per sq. in.	10·2	—	12·3	11·7
Yield-point, tons per sq. in.	14·1	20·1	15·5	15·9
Ult. Stress, tons per sq. in.	36·4	40·7	38·8	39·4
Elongation, %	68·5	49·0	57·5	62·5
Reduction of Area, %	83·5	65·5	77·8	75·7
Brinell Hardness	149	156	153	153

The short-time high-temperature properties of these steels were determined at an extension of 0·017 in. per min. up to the yield-point, and at an extension of 0·053 in. per min. above the yield-point over a range of temperature from 425° to 1,200° C. after air-cooling from 1,080° C. Elevated temperature tests were also made on steel A after normalising at 830° C. The data obtained from these tests showed ultimate tensile strength to fall off uniformly and regularly for all the steels, but the yield-point increased and the reduction of area and elongation decreased at 650° C. for steels air-cooled from 1,080° C. Steel A, air-cooled from 830° C., did not show those changes, but when tested at elevated temperatures using a recording extensometer showed that yielding, not noted at 650° C., occurred by a rapidly recurring succession of slips at 600° C. and above, and less notably and of lower frequency at 540° and 475° C., and was only slightly discernible at 425° and 315° C.

From the curves obtained from the elevated temperature data of the three steels, it was shown that ductility at hot-working temperatures does not increase with reduction in carbon, but increases with increase in manganese. This beneficial effect of manganese has been confirmed by much experience in hot-working the alloy, and for tube steel, manganese of about 1·6% is suitable. Higher manganese steels have much better ductility in the hot-working range 1,100° to 1,200° C. It has been suggested that the poorer working qualities of the low manganese steels are due to precipitation at the grain boundaries of a complex sub-microscopic oxide of chromium, since hot workability is improved by the addition of a considerable amount of manganese, or of small amounts of aluminium or zirconium. Such additions would tend towards the reduction of, or the prevention of the formation of the chromium oxide. The precipitation of such a compound is also a distinct phenomenon from that of carbide precipitation at 600° to 650° C.

TABLE II.

Rate per 1,000 Hours %.	540° C.	650° C.	730° C.	815° C.
18% Cr—8% Ni—(low carbon).				
0·01	11,500	4,250	1,600	—
0·10	18,300	6,600	2,500	—
16% Cr—13% Ni—3% Mo.				
0·01	14,800	5,000	2,500	930
0·10	22,800	8,200	4,200	1,840
25% Cr—20% Ni.				
0·01	—	5,400	2,700	800
0·10	—	7,400	3,300	1,100

As preliminary creep tests on the laboratory prepared steel containing 0·11% carbon showed good results, more extensive creep tests were carried out on the commercial steel A containing 0·07% carbon after air-cooling from 830° C. In Table II the creep properties of steel A are compared with those of 18 : 8 and 25 : 20 chromium-nickel steel, and show the influence or molybdenum on the high-temperature properties.

The creep properties on the experimental steel containing 0·11% carbon being better than those obtained with the 0·075% carbon steel, it was considered desirable to investigate those of the higher carbon grades for elevated temperature use. Steels A, B and C in 9 in. long by 1 in. diameter pieces were therefore heat-treated in two ways, first for 1 hour at 940° C. and air-cooled, and second for 1 hour at 1,065° C. and air-cooled, and then subjected to impact and hardness tests. Standard Charpy drilled keyhole notched specimens were prepared from the six lots, heated at 600°, 650°, 700°, and 750° C. for 100, 500, 1,000, and 1,500 hours, and after these exposures to prolonged heating, the Charpy impact values and the Rockwell B hardnesses were determined. No temperature or time of heating used reduced the impact resistance to less than 38 ft.-lb., nor raised the hardness to more than 98 Rockwell B. Carbide precipitation varied with the carbon content, the initial treatment, and the grain size, but as the time of heating was prolonged the structure and properties of any one steel tended to become alike, irrespective of initial grain size or of which heat-treatment was applied. A steel containing 0·06% carbon, 17% chromium, 13% nickel, 3% molybdenum, when compared with a steel containing 0·06% carbon, 19% chromium, 9% nickel, 3% molybdenum was also found to show superior toughness when tested for hardness at ordinary temperature and after heating and for impact (Charpy V notch) resistance at elevated temperatures.

A 16% chromium, 13% nickel, 3% molybdenum steel containing 0·11% carbon is found to have increased susceptibility towards aequous corroding agents after long-continued exposure to temperatures in the 600° to 750° C. range. Experience has shown, however, that corrosion of this type is not encountered on the usual cracking or other process used on oils, and that hydrocarbon gases providing condensation of moisture do not take place on external surfaces of tubes during inoperative periods. Hence it appears that creep strength of the 0·11% carbon alloy might be used for equipment in such processes, provided proper precautions are taken for removing sulphate deposits from tube surfaces and oiling during shut-down periods. If such procedure is impractical, it would be desirable to use the 0·07% carbon alloy, thereby sacrificing some creep strength to gain lessened susceptibility to corrosion due to carbide precipitation effects.

Local Formation of Martensite on the Surface of Rails

AN investigation of surface defects in some rails laid on a steep incline is described by Bozié.† An examination of the microstructure revealed that martensite had formed at places where the severe application of locomotive brakes had caused overheating, with subsequent sudden cooling by the surrounding mass of the rail.

Properties of Nickel and Nickel-containing Materials

This is the latest publication issued by the Mond Nickel Co., Ltd. It contains technical data on practically all the more important nickel alloys, both ferrous and non-ferrous. It contains 40 pages, each of which can be regarded as a data sheet. It gives essential information on constructional and case-hardening steels ; Staybrite and S80 steels ; heat-resisting steels ; cast steels ; Ni-Resist ; Ni-Hard and Ni-Tensyl-Iron ; nickel iron ; magnet alloys ; copper-nickel alloys ; Monel, "K" Monel, Inconel and nickel ; nickel silver ; nickel bronzes ; non-ferrous alloys at elevated temperatures ; nickel-chromium ; aluminium base alloys containing nickel ; Centigrade-Fahrenheit equivalents ; and the third page of the cover carries a useful index.

The information presented in this publication has been carefully revised and brought up to date, and, in its present compact form, it will be invaluable to members of designing staffs and others who require technical information to assist them in specifying materials. Copies may be obtained, free of charge, from the Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W. 1. Individuals should give the name of their firm or state the nature of their interest.

† *Stahl und Eisen*, **60**, pp. 756-746.

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A Ministry of Production

By ELLIS SMITH, M.P.

The increasing intensity of the present struggle necessitates greater concentration of industry to meet the essential requirements of our various Forces and to supplement the requirements of our Allies. Nothing should be allowed to retard our war effort. Since production is playing such a vital part in the conflict, planned organisation of industry under a suggested Ministry of Production is receiving much attention, and this discussion of the subject is of more than usual interest.

IN the speeding up of production for the war machine, we are trying to do in months what Germany accomplished in years. The outbreak of war found us almost hopelessly unprepared in equipment for the Forces, and even in the early months of the war much valuable time was lost by a want of successful planning of production. In the House of Commons, as far back as 1936, I emphasised the importance of securing an adequate supply of machine tools in order to be ready to facilitate production in the event of this country being involved in war. Reference to Hansard's for 1937, 1938, and 1939 will show how often I raised that matter. Stimulated by the increasing gravity of the international situation, by reading of the evidence placed before the Royal Commission that investigated the private manufacture of armaments, and by personal experience, an adequate supply of machine tools seemed to me to be essential. My warnings prior to the outbreak of hostilities remained unheeded, but the growing interest in the importance of machine tools since September, 1939, has been some consolation. What a lesson there is in the treatment of this key industry!

For somewhat similar reasons there was unnecessary delay in setting up a Ministry of Supply, of which the Prime Minister was one of the keenest advocates; the Government avoided it as long as possible, and when finally decided upon, the Ministry was set up in a compromised form. That should be remembered and fully appreciated when consideration is being given to the problem of production.

The situation demands the formation of a Ministry of Production, and if anyone doubts this I ask him :—

Are you satisfied with production?

Are we obtaining the maximum output?

Is the machinery satisfactory?

In view of the enormous wastage in modern large-scale warfare, do you consider we are producing spare parts on an adequate scale to effect efficient repairs as quick as circumstances demand?

In the main, I believe that both managements and work-people are sound, but have we harnessed their spirit and determination to obtain the maximum output in the minimum of time?

In his dispatch from the battle-front, a few days ago, a Russian General expressed himself in these words :—

"The Germans have more tanks than we have, and they are taking the utmost advantage of this fact. They are hurling these tanks against our defences everywhere, along the whole front. How much courage and coolness, how much fortitude and valour are required to stand up to, without faltering, and to repulse the attack of these armoured monsters."

That helps us to place the importance of accelerated output in its proper perspective. But it only emphasises the views of many who know the demands made by modern warfare. Even in 1932 the German General von Metzsch said: "It was not the genius of General Foch that beat us, but General Tank"; while a German colonel wrote: "Four weeks' drum fire, a four-months' pitched battle with 400,000 casualties, gained for the British, in 1917, a strip of land 9 miles by 5 miles. Yet at Cambrai, with 400 *tanks* and a loss of 400 men, they achieved similar results in 12 hours."

Our problem is to produce more than the Continent of Europe, which Germany controls, and let none minimise the seriousness of the task, nor the fact that the danger of catastrophe still remains. We must increase our output of aircraft and it can be done. We must have tanks, tanks, and more tanks, until the ratio is two-to-one in our favour, and our output must be superior qualitatively. We must be ready to ensure that these tanks will be in a serviceable condition after travelling hundreds of miles; adequate spare parts therefor must be available for each tank supplied.

Another problem of immediate concern is the movement or replacement of industrial capacity that is likely to be or may be put out of action by an attempted invasion. A solution is urgent and imperative.

These and other major problems convince me that our needs demand the appointment of a Ministry of Production, with full authority and supported by an organisation capable of co-ordinating all the branches of war production. What is known as the "Star Plan," prepared by Mr. George Dickson, is, I believe, the best of its kind and should receive the careful consideration of the Government and all interested in production. But my personal view is that a British Production Plan should be prepared, and the following action should be taken without delay :—

1. A Minister of Production should be appointed and given complete authority over all industrial capacity, resources, and over all supplies required in production.
2. The Ministries of Supply, Aircraft Production, and the Admiralty shall carry on with their activities, but they shall be subject to the authority of the Production Ministry.
3. The Minister of Production, being a member of the War Cabinet, will be aware of strategy, immediate and long-term needs, and should have prepared a plan that will provide efficient organisation and mobilise all industrial capacity and resources in order to obtain the maximum output in the minimum of time.
4. All factories, steel plants, etc., should become Controlled Establishments, and should be organised to give the best results in the national interests.
5. There should be formed a National Production Board, members of which to be selected, not because of their social status, but because of their competence, experience, drive, energy and ability to secure the maximum output; it should not be composed of representatives.
6. Regional Production Boards with local committees should be formed on the basis of the best geographical output area. The organisation should be run

by men who know modern industry and can secure the best results. The present regional and area committees to be superseded by the Production Ministry machinery.

7. The Production Board should form a corps of young production engineers who will be given full authority to survey all industrial capacity and to take such steps as will achieve the best results in the national interests.
8. Works' Councils, fully representative of all organised interests, should be set up in every factory and shall meet at least once a week.

A fundamental factor in any plan adopted should be decentralisation; even if no plan is adopted, and we carry on as we are—which I hope we do not—decentralisation is vital. Further, we should aim at the elimination of sub-contracting, which is not efficient.

A highly placed civil servant, during the last war, Mr. E. M. H. Lloyd, gave his experiences in a book entitled, "Experiments in State Control," and on one page he states: "I believe that to wage war effectively involves replacing private enterprise by collective organisation."

Along that road I believe is the way to increased output. We cannot win this war by words, resolutions, wishes or hopes, but we can win it if we will mobilise our industrial capacity on a planned basis and build an organisation worthy of the spirit and determination of the British people.

Wrought Light Alloys Development

Aluminium unites readily with a large number of metals to form useful alloys. One or several elements may be added to aluminium, and, in consequence, a very large number of aluminium alloys has been developed in addition to well-known compositions and proprietary alloys, with the result that the user of aluminium alloys is often in a quandary in selecting the most suitable alloy for his particular purpose from the great number that are available. Even when a satisfactory selection has been made, the difficulties of the user are not by any means at an end, as a special technique is generally necessary to obtain the desirable properties in the component for which the alloy is chosen.

Aluminium alloys are broadly classified in two main groups:—

1. The ordinary alloys, which are used without heat-treatment.
2. The heat-treatable alloys, which depend upon some form of heat-treatment for improvement in their physical properties.

The aluminium alloys of high strength generally belong to the second group, but they are more difficult to work than the less strong non-heat-treatable alloys. Difficulties encountered in the manipulation, heat-treatment and finishing of some of these alloys, particularly in works in which they have not previously been used, have caused many production problems. That they have arisen is due largely to lack of experience and to some extent from the scarcity of information regarding the technique required; further, there exists a shortage of personnel trained to deal with light alloys and conditions do not permit suppliers to give users the detailed attention available in normal times. To overcome these difficulties, an Association has been formed which places its technical services at the disposal of any fabricators or users of aluminium alloys having problems which cannot be solved in their own works.

This Association is known as the Wrought Light Alloys Development Association, and while it has been formed primarily to promote the increased application of the strong aluminium alloys, for the present it has adopted as its main policy the dissemination of all available information on the physical, mechanical and working properties of these materials in order to assist the war effort to the fullest possible extent.

The great development in the use of aluminium alloys is due largely to their inherent properties and their ready adaptability to industrial requirements, but an important contributing factor has been the intensive work carried out to develop successful methods for the production of material or components from the alloys. All the main developments in the manufacture of aluminium alloys have been followed by careful work to develop a suitable working technique, whether for rolling, forging, extrusion, etc., and the work of this Association will be invaluable in facilitating fabricating operations by dealing with technical problems encountered.

It is noteworthy that one of the first tasks has been to set up an Advisory Service Bureau capable of dealing with difficulties that may be encountered more particularly with wrought aluminium alloys. Backed by the experience of the producers and many of the largest users, this consultant service is able to provide reliable information for any user, however small. Inquiries, which should be accompanied by sample whenever possible, must include full details as to the material, the operation involved, any remedial measures which have been tried, and any other information considered relevant.

The Association is in touch with progress, and developments in fields directly or indirectly affecting the employment of wrought light alloys, and collects and collates all available information for dissemination by publication and other means. Research projects will also be sponsored by the Association from time to time with a view to extending knowledge of the aluminium alloys and investigating new applications.

Incorporated as a company early this year, the Association comprises the principal manufacturers of wrought light alloys in this country. Dr. E. G. West, who has had a varied experience of the light alloys, recently took up the position of manager, to whom all inquiries should be sent at the office of the Association, 34, New Street, West Bromwich.

The Replacement of Drop Forgings and Pressings by Welded Parts

In view of the pressure being applied to the manufacturers of drop forgings and pressings and the difficulties being encountered to satisfy the increasing demands for these components with the facilities available, the Ministry of Supply recommends users to investigate the possibilities of using welded components to replace drop forgings and pressings where possible. Welded steel machine parts can be used in place of steel forgings and pressings because:—

1. There is no shortage of welding facilities.
2. Standard steel sections for welding are available.
3. Machining time is reduced by the use of welded parts.
4. Strength and stiffness may be obtained with a minimum of weight by the proper placing of the material.
5. Dies and patterns are not necessary.
6. The possibility of delay in production by loss of dies and patterns is avoided.
7. Advanced alteration of design may be readily effected.

Recommendations are made in Welding Memorandum No. 5, which has just been published by the Advisory Service on Welding, and which illustrates a few of the many types of machine parts capable of being readily produced by welding standard steel sections. Contractors desirous of changing the design of components to make use of welded structures are advised to submit their proposals to the authority responsible for inspection. Copies of this memorandum may be obtained from Great Westminster House, Horseferry Road, London, S.W. 1.

The Salt-Bath Method for the Patenting of Steel Wire

D. W. Rudorff, A.M.I.E.E., M.Inst.F., F.R.S.A

The use of salt baths for patenting steel wire is not new, but several difficulties encountered have interfered with their more general application. Much progress, however, has been made in this direction in recent years, largely as the result of a careful study of the subject, and in this article some recent investigations are reviewed and the resulting progress is discussed.

WHILE still adhering to the basic principle of patenting steel wire, embodied in the invention of James Horsfall some sixty years ago, much research has lately been carried out with a view to achieving further refinement of this heat-treating process. Considering the importance of the patenting process as part of modern steel wire manufacture, a short review of recent progress made in the execution of this process may be of interest.

With regard to the heating phase preceding the process proper, the introduction of electric resistance heating must be considered as constituting the most noteworthy recent advance. The general working principle of this method consists in securing uniform heating of the entire cross section of the wire by passing a carefully controlled electric heating current through the wire itself, prior to its passage through the lead pot. Exhaustive reports of experiences gained with this arrangement are available in technical literature,[1] and need not, therefore, be reiterated here.

Repeated attempts have been made in recent years to replace the customary liquid lead bath by a salt bath, and a number of such installations are now in commercial operation in various countries. In consideration of an increasing scarcity of lead in war-time Germany, two investigators in that country have recently undertaken an extensive study of the salt-bath method in order to facilitate its general introduction into German practice. This investigation[2] proceeded from the fact that in order to produce the desired sorbitic structure, unalloyed steel wire with more than 0·4% carbon content requires a quenching velocity of approximately 100°–200° C. per second from initial temperatures ranging between 650° to 600° C. In current German practice, this is achieved by passing the heated wire through a lead bath kept at 400°–550° C., the precise temperature to be employed depending upon such factors as carbon content, wire diameter, and travelling speed of the wire through the lead pot.

In order to arrive at a suitable salt-bath method to serve as substitute for the lead pot treatment, a thorough study of the cooling power of various salt baths as well as of the comparative cooling powers of salt and lead baths, was deemed necessary. Making use of the results of previous investigations carried out by N. Engel and A. Rose,[3] measurement of the cooling power was carried out by means of the immersion probe method in which the temperature drop in the centre of a solid metal ball is measured by an interior thermocouple. The probe used by Engler and Rose consisted of pure silver, in order to reduce time lag to a minimum. For the purpose in question, however, silver was not considered suitable, because of the high initial temperature of the bath and also because silver would alloy with the lead. A non-scaling and thermally stable steel of the silicon-chromium-aluminium type ("Sicromal") therefore was chosen instead. The diameter of the probe was made 12 mm., the thermocouple wires being led through the attached hollow stem. The electromotoric force generated by the thermocouple, and with it the temperature in the centre of the probe, was recorded by means of a recording galvanometer incorporating a time-registering device.

In the case of the four types of bath investigated—i.e., lead, potassium nitrate, sodium nitrate, and a mixture of equal parts of potassium nitrate and sodium nitrate, two series of tests were run, the one with an initial temperature of the probe of 800° C., and the other of 950° C. For the lead bath and the two unmixed salts, bath temperatures of 350°, 450°, and 550° C. were tried out, an additional test at 250° C. being run with the salt mixture. Heating of the probe was carried out in an electric muffle furnace, the electrically heated bath pots being placed in front of the furnace. Upon immersion in the bath, the probe was kept in slow-stirring motion by moving it in a circle at a uniform speed of approximately 10 cm. per second.

Before undertaking the test runs proper, it was considered important to ascertain whether any irregularities arising from vapour formation and boiling during the cooling process would be recorded by the galvanometer, in spite of the relatively poor heat conductivity of the steel probe. For this purpose an oil-quench test was made with the probe at 800° C. at initial temperature and the oil bath at 20° C. The results of this test, charted in Fig. 1, indicate that the steel probe gives fully satisfactory results, as the two curves obtained with oils Nos. 2 and 3 clearly show the occurrence of a vapour phase with subsequent boiling. A comparative test run with a silver probe of 20 mm. diameter, immersed in oil No. 3—charted in Fig. 2—shows that with the more sensitive silver probe the maximum of cooling speed occurs at the same temperature indicated in Fig. 1 (curve 3). While it is evident from Figs. 1 and 2 that the silver probe yields a more sharply pronounced maximum of quenching speed, it is equally evident that the temperature sensitivity of the steel probe is quite sufficient for the purpose in question.

The cooling capacity of the liquid lead bath found with the use of the steel probe is charted in Fig. 3. According to this graph, the cooling rate rises upon immersion rapidly to its maximum value, whereupon it decreases at first slowly and then falls off to zero with increasing rapidity. It is seen that the maximum values of the cooling rates attained, increase with the initial temperature difference prevailing between probe and bath. As it must be expected, these cooling curves show no irregularities, since boiling or Leidenfrost phenomena do not occur with a lead bath. It is also seen that increasing initial temperature difference between probe and bath tends to extend the range in which merging occurs of the curves obtained with 800° and 950° C. respectively.

As Fig. 4 shows, the cooling characteristics of the salt mixture are quite different from those obtained with the lead bath. Although the curves recorded for various initial and bath temperatures exhibit the same mutual similarity as is encountered with the lead bath, the influence of the initial temperature difference upon the cooling effect is clearly less pronounced. A noteworthy feature of the curves of Fig. 4 is the fact that, once the cooling rate has passed its maximum, it begins to decrease rapidly in almost

1 O. C. Trautman. "Electric Direct Resistance Patenting and Tempering of Spring Wire." *Wire and Wire Products*, Nov., 1937, p. 711–714: Dec., 1937, p. 767–771. See also J. W. Morrison. *Iron and Steel Eng.*, vol. 16, 1939, No. 12, p. 28–36.

2 W. Lueg and A. Pomp. "Verwendbarkeit von Salzbaedern zum Patentieren von Stahldraht" (Applicability of salt baths to patenting of steel wire). *Stahl und Eisen*, March 13, 1941, p. 266 *et seq.*

3 N. Engel. "Ingeniørvidenskabelige Skrifter." A, No. 31, 1931, Copenhagen, 1931. A. Rose, Mitt. K.W. Inst. Eisenforschung, vol. 21, 1939, p. 181–196.

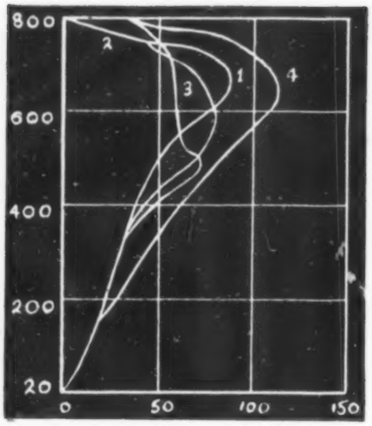


Fig. 1.—Cooling rate of 12 mm. dia. steel probe versus initial temperature of the probe for various mineral oils (1, 2, 3) and for rape oil (4) at a bath temperature of 20° C.

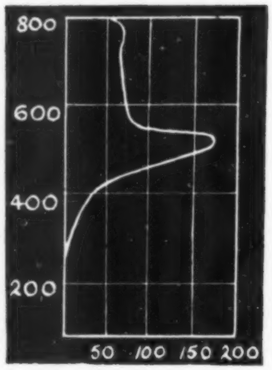


Fig. 2.—Cooling rate of 20 mm. dia. silver probe versus initial temperature of the probe for mineral oil (3) at a bath temperature of 40° C. (according to A. Rose).

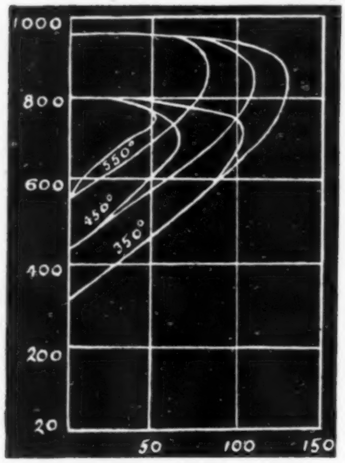


Fig. 3.—Cooling rate of 12 mm. dia. steel probe versus initial temperature of the probe for lead pot temperatures ranging between 350°–550° C.

straight-line relationship with the temperature decrease in the centre of the probe. At approximately 600° C., all curves show a sudden, although moderate, change in direction, the lower branch of the curve again showing the aforementioned straight-line relationship until a zero cooling rate is finally reached upon descent to the bath temperature. This sudden change in cooling effect must be considered as pointing to the occurrence in the cooling medium of some sort of chemical or physical phenomenon. That it is not due to the use of a steel probe, was proven by comparative tests run with the silver probe, which tests showed an identical inflection in the same temperature range. The merging of the upper branches of the cooling rate curves obtained at identical initial temperature with varying bath temperature as it occurs in the case of the lead bath (Fig. 3), is also exhibited by the curves in Fig. 4. But here the concurrence of the curves is seen to extend over a wider range.

The cooling effect characteristics obtained with the individual salts were found to be practically identical with those of the salt mixture, and this applies also to the inflection of the cooling rate curves in the 600° C. region as observed with the salt mixture bath. A comparison of the cooling power of lead and salt baths shows that the cooling effect of the salt baths is somewhat below that of the lead bath at identical initial and bath temperatures. This difference is particularly noticeable in the region of sorbite formation from 650°–600° C. When using this type of salt bath for the patenting of steel wire, it therefore appears necessary to employ a bath temperature somewhat lower than is considered appropriate with the use of the lead pot.

In order to ascertain the influence of the stirring speed upon the cooling rate, a series of test runs was made with 950° C. initial and 450° C. bath temperature—(*a*) without stirring, (*b*) with moderate stirring, and (*c*) with high stirring speed. The results of these tests are charted in the graph reproduced in Fig. 5. Here it is seen that the influence of the stirring speed upon the cooling effect is very considerable in the case of the lead bath, the cooling rate and cooling effect with moderate stirring lying about 30%, and with fast stirring by about 70% over and above the corresponding values obtained without stirring. Quite different conditions were found to prevail in the case of the salt bath. While here the maximum cooling rates with moderate and rapid stirring were found to be 9 and 15% respectively higher than with keeping the probe stationary, the stirring speed proved to be almost without any influence within the temperature range from 700° C. down to the equalisation temperature of 450° C. As long as the initial temperature of the wire is maintained constant, changes in the speed at which the wire travels through a salt bath will therefore be of little consequence.

A still better insight into the quenching process is gained from expressing the cooling rate as a fraction of the initial temperature difference, and charting the momentary temperatures prevailing in the centre of the probe as

Fig. 4.—Cooling rate of 12 mm. dia. steel probe versus initial temperature of the probe with salt-bath temperatures of 250°–550° C.

Fig. 5.—Influence of the stirring speed on the cooling rate of a 12 mm. dia. steel probe of 950° C. initial temperature introduced into a lead pot of 450° C. bath temperature, S : probe stationary ; M : stirring speed 10 cm./sec. ; F : stirring speed, 30 cm./sec.

Fig. 4

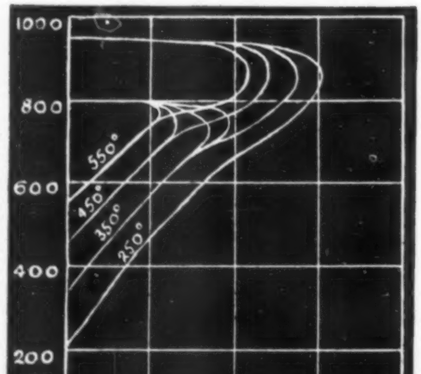
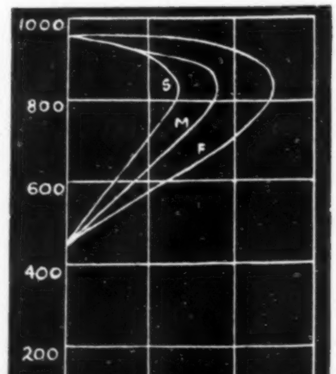


Fig. 5



percentages of the initial temperature margin. This type of graph is given in Figs. 6 and 7, in which the relative cooling rates recorded for lead and salt baths are charted for an initial temperature of 950° C. with the three bath temperatures of 350°, 450°, and 550° C. Referring to Fig. 6, it is seen that in the case of the lead bath practically identical characteristics are obtained with the different bath temperatures. This indicates that the cooling power of the liquid lead bath changes to the same extent by which initial temperature margin between the probe and the bath is changed, if all other conditions are left unchanged.

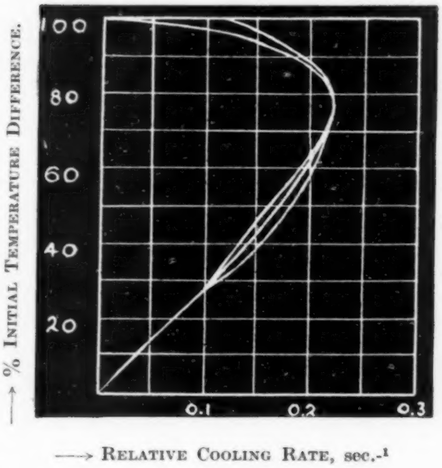


Fig. 6.—Relative cooling rates from 950° C.; initial temperature for lead pot temperatures ranging from 350°–550° C.

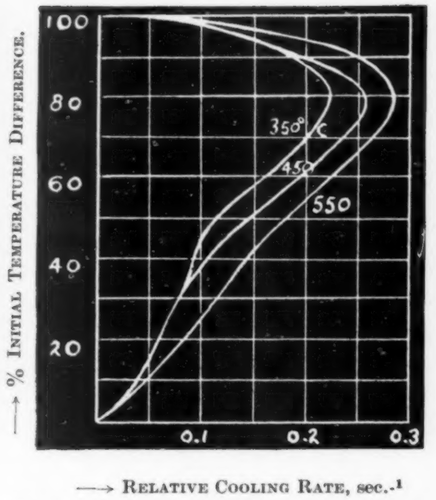


Fig. 7.—Relative cooling rates from 950° C.; initial temperature for salt-bath temperatures ranging from 350°–550° C.

An analysis of these results was found to show that the coefficient of heat transfer between the probe and the lead bath does not undergo any changes during the quenching process, this coefficient remaining at a constant value of approximately 1,000 B.th.u. per sq. ft. per ° C. difference per hour; and it remains also constant irrespective of the initial temperature margin employed.

The chart given in Fig. 7 shows that a relationship of this kind does not exist in the case of the salt bath. Here the relative cooling rate (and with it the cooling power) is seen to increase with diminishing initial temperature margin. Also, the heat transfer coefficient was observed to undergo considerable changes with variations in the initial temperature margin as well as during the cooling process itself. It therefore is well-nigh impossible to establish any fixed values for the coefficient of heat transfer obtaining between the surface of the probe and the liquid salt.

In order to ascertain whether it is permissible to apply the conclusions drawn from the aforementioned investigations to commercial patenting operations, several lengths of 0·58% carbon wire of 4 mm. diameter were patented in lead bath and salt mixture at initial temperatures of 850° and 970° C., the bath temperatures being varied from 250°–550° C. The wire used was a patented product of 142,000 lb. per sq. in. tensile strength. Prior to the test, this strength was reduced to 113,600 lb. per sq. in. by normalising. The various lengths of wire were heated to the test temperature in an electrically heated furnace in which a protective atmosphere was maintained. After heating, the wire was quickly immersed in the bath, with a slight stirring motion being maintained. Subsequent cooling to room temperature was effected in air. Microstructure investigations proved that both types of bath produced practically identical metal structures. However, as the wire samples were not long enough to allow an exhaustive investigation of the various physical properties of the material after patenting, only the effects of the quenching media and of their bath temperatures upon the tensile strength of the material could be ascertained.

The numerical results of this examination are given in het accompanying table. According to this, almost identical values of tensile strengths are obtained for both quenching media at bath temperatures of 550° and 450° C. and with identical initial temperatures. With this range of bath temperature, the tensile strength obtained approximates to that of the wire in its original patented condition. Lowering of the bath temperature below 450° C. in the case of the lead bath, and below 400° C. in that of the salt bath, led to progressive increases in tensile strength. It is interesting to note that at temperatures below 450° C. the greater cooling power of the lead bath is evidenced by the attainment of superior tensile strength. In order to obtain equal tensile strength with the use of either bath, it is therefore necessary to keep the temperature of the salt bath approximately 25° C. below the corresponding temperature of the lead bath.

INITIAL WIRE TEMPERATURE, 860° C.

Bath temperature, ° C. ...	250	300	350	400	450	500	550
Tensile Strength, '000 lb. per sq. in.— Lead bath	—	—	213·0	177·4	142·0	142·0	136·3
Salt bath	312·0	245·7	187·5	156·5	146·3	142·0	130·0

INITIAL WIRE TEMPERATURE, 970° C.

Bath temperature, ° C. ...	250	300	350	400	450	500	550
Tensile strength, '000 lb. per sq. in.— Lead bath	—	—	—	166·2	144·9	142·0	139·2
Salt bath	—	245·7	198·8	150·5	143·4	144·8	136·3

The conclusions drawn from the investigations conducted with the steel probe were found to be fully confirmed by the actual patenting tests. In the report under review, stress is laid on the fact that (as the tabulated values show), the influence of the bath temperature within the range of 450°–550° C. is small and that the variation in initial wire temperature from 860° to 970° C. at the bath temperatures concerned, had no important influence upon the tensile ttrength of the patented product. It is further reported shat full scale application of the salt-bath method has, however, revealed certain practical difficulties. These were mainly due to the adherence of salt to the wire, thereby interfering with the drawing of the patented product. A strong tendency of the wire towards rusting was also noticeable. According to E. Jaenichen,[4] difficulties of this kind can be eliminated by the use of a salt-bath mixture consisting of—

80% Sodium Nitrate.
12% Sodium Nitrite.
8% Sodium Chromate.

The melting point of this mixture is about 280°–300° C. The mixture does not show any tendency to ignite at 650° C.; nevertheless, oil or coke ovens must not be used for heating the mixture, since in the event of accidental leakage of the pot, contact between the nitrites of the mixture and the coal or oil coke would lead to an explosion. For the sake of operating economy, salt adhering to the wire and subsequently cracked off, should be returned to the pot. The salt consumption is reported to be about 0·7 kilog. per ton of wire, as compared to a corresponding lead consumption of 5 kilog. per ton.

Finally, it may be mentioned that a recent German patent granted to the I.G. Dye Trust, refers to the use of a bath of potassium-chromate and potassium bichromate which is claimed to exclude the danger of corrosion.

4 See Appendix to 2.

Chemical Reactions as an Aid to Machining

The Influence of Solutions of Electrolytes on the Rate of Grinding of Metals

By A. Behr, B.Sc.

In the past so much emphasis has been placed on the purely mechanical aspects of machining processes that the influence of other factors has, to a great extent, been overlooked. Practical experience and, more recently, fundamental research has shown the influence of friction, and this has necessitated a consideration of the effect and action of lubricants. In this article the author reviews an investigation on the influence of factors, other than purely mechanical, on the process of grinding metals.

At present it is generally recognised that the mechanical properties of a metal exert some influence on the processes of machining the metal, and attempts have been made to relate certain mechanical properties to certain other characteristics used to measure, at any rate, one of the factors comprised in the term machinability. That the mechanical properties should exert a predominating influence on what may be termed bulk machining operations is fairly clear. At the same time, practical experience and, more recently, fundamental research, have shown how important is the influence of other factors, such as, for example, the friction between the metal and the cutting tool. Friction itself being a complex property, one is quite naturally led to more fundamental investigations, involving a detailed consideration of surface structure and properties and the effect and action of lubricants. Any consideration of the effect and function of lubricants cannot remain an entirely mechanical one. Questions regarding adsorption or chemisorption and, in some cases, actual chemical reaction between the metal surface and the lubricant will invariably be involved in any comprehensive examination of the problem.

If, now, the whole gamut of what may be termed surface effects have to be considered when dealing with bulk machining, it is to be expected that their effect will become relatively more and more important as the volume of the metal involved in the particular machining operation becomes smaller and smaller, and more and more restricted to layers nearer the surface of the metal. Indeed, in the limit, machining may well become a physico-chemical process or, more precisely, a spatially restricted chemical reaction.

An initial realisation of this statement is to be seen in the development of the electropolishing processes. Originating from laboratory applications to metallographic specimens, these processes are undoubtedly entering upon an era of extending commercial use, a use, however, which it appears is rendered difficult, if not actually hampered, by the absence of any generalised theory and practice.

Unfortunately, in the past, the emphasis has been placed too much on the purely mechanical aspects of machining processes, and any other considerations have been more or less overlooked, even in such matters as the choice of lubricants.

It is the object of this article to review one very interesting, though comparatively unknown, investigation on the influence of factors, other than purely mechanical, on the process of grinding of metals. In the first part of their investigation, A. G. Samartsev and V. P. Lavrov,* studied the influence of aqueous solutions of different electrolytes on the grinding of various metals.

A glass disc driven by a constant-speed electric motor was used as the grinder. As abrasive, a suspension of carefully fractionated emery powder in water or in an aqueous solution of an electrolyte was used. The suspension was kept well stirred and a constant stream of it was supplied to the grinder. The amount of metal ground away was determined by weighing. In addition, a dynamometer was used to measure the frictional force between the grinding disc and the surface of the metal being ground, and in this way it was possible to determine the amount of work required to grind away a given amount of metal. The tests were carried out on iron (low-carbon), nickel, stainless steel, silver and copper.

The results obtained with iron are shown in the following table :—

TABLE I.

Electrolyte.	M Mg	F *g*	*m* Mg/Kg.m.
Water	26	277	0·62
Na_2CO_3	28	289	0·70
Na_2SO_4	31	296	0·69
NH_4Cl	33	303	0·75
KI	35	296	0·80
$AlCl_3$	34	294	0·79
$K_4Fe(CN)_6$	47	307	1·05
$K_3Fe(CN)_6$*	77	313	1·70
$Fe_2(SO_4)_3$*	90	298	2·13
$FeSO_4$	33	298	0·78
$CuSO_4$	215	337	4·95
$HgNO_3$(1)	34	285	0·85

1 Solution acidified with HNO_3.

In the table, M is the weight of metal ground away in mg by 360 turns of the grinding disc at a speed of 12 r.p.m. ; F is the force of friction in *g* between the grinding disc and the specimen, and *m* is the weight in mg of metal ground away per 1 kilog. of work done.

The concentration of all electrolytes was 1 g. equivalent per litre.

For each determination, the apparatus was charged with an abrasive consisting of 50 g. of 60-min. emery powder suspended in 50 ml. of the electrolyte, and three successive determinations were made. In the table the mean results of the three determinations are given, except those marked with an asterisk, which are the results of the first determinations.

From the data in the table, it will be seen that the amount of metal ground away varies considerably with the electrolyte added to the suspension of abrasive material, whereas the force of friction only varies within very narrow limits. This caused the authors to give up the measurement of the force of friction and to determine the influence of the electrolyte, in subsequent experiments only by changes in the value of M, which may be referred to as the rate of grinding.

The rate of grinding of iron is affected most by solutions of $K_3Fe(CN)_6$, $Fe_2(SO_4)_3$ and $CuSO_4$. In all these cases chemical solution undoubtedly takes place, and the rate of grinding is apparently, it is suggested, determined by local cells set up on the surface being ground. It is interesting to note, however, that the surface of the iron ground in solutions of these electrolytes does not differ in any way from that of iron ground in water.

As the amount of electrolyte acting on the surface

* *Zhurnal Tekhnicheskoy Fiziki (Journal of Technical Physics*, U.S.S.R., VII, 1937, No. 1, pp. 24-29).

decreases during the grinding process, so the rate of grinding is reduced. This is shown by the results in Table II.

TABLE II.

Electrolyte.		M Mg.	Electrolyte.		M Mg
$K_3Fe(CN)_6$	1st deter.	77	$Fe_2(SO_4)_3$	1st deter.	90
,,	2nd ,,	70	,,	2nd ,,	54
,,	3rd ,,	66	,,	3rd ,,	40
$K_4Fe(CN)_6$		47	Fe_2SO_4		33

The suspension of abrasive was not renewed for the successive determinations. For comparison, the rates of grinding in solutions of electrolytes which are the products of reduction of $K_3Fe(CN)_6$ and $Fe_2(SO_4)_3$ are also given.

In general, it will be seen from Table I that grinding is accelerated by electrolytes which are most corrosive to iron. The slight effect of $HgNO_3$ solution is probably explained by the fact that some amalgamation of the surface takes place which renders it comparatively electrically homogeneous.

In the case of nickel, the value of M changed comparatively little from one electrolyte to the other. Even in a solution of $CuSO_4$, the rate of grinding remained practically the same as in water. The most effective electrolytes were KI and $K_3Fe(CN)_6$, in which the values of M were 36 and 68 mg. respectively.

Stainless steel behaved in much the same way as nickel, solutions of KI and $K_3Fe(CN)_6$ again being the most effective. The observed behaviour of both nickel and stainless steel is undoubtedly connected with their chemical passivity.

While the experiments with silver and copper were carried out under slightly different conditions and the results cannot, therefore, be directly compared with the previous ones, they are, nevertheless, of considerable interest, particularly in the case of silver. The results obtained with the latter are given in Table III.

TABLE III.

Electrolyte.	M Mg.
Water	8·4
KCl (Normal solution)	3·3
KBr ,,	6·4
KCNS ,,	11·8
KI	19·4
K_2SO_4	20·3
KNO_3	26·4

The results in Table III show very clearly how the rate of grinding of silver depends to a considerable extent on the anion of the electrolyte present in the suspension of abrasive material. It might have been assumed that this could be connected with the rate of oxidation of the surface of the metal, as the action of air was not eliminated in these experiments. However, analysis of the ground-off slime showed that the greater part of the silver ground-off was not in the form of oxides or silver salts, but in the form of finely divided metal.

Another interesting observation made in these experiments was concerned with the rate of grinding away of the glass-grinding disc. In the experiments with silver, the area of the disc was equal to the area of the metal specimens and it was found that independent of the nature of the electrolyte, and irrespective of the large variations in the rate of grinding of the silver, the rate of grinding of the glass remained constant and equal to 11 mg.

The results obtained for the rates of grinding of silver could not be fully explained at the time. The investigators suggested that the difference in stability of the silver surface in the different solutions of electrolytes could perhaps be related to the different adsorbability of the different anions on the surface of the silver. As the specific adsorbability of the anions increases in the order $Cl < Br < CNS < I$ one may expect that the surface tension of the metal will decrease accordingly, and with it the stability of its surface in these electrolytes.

Oxidation of the metal may, however, play a part in certain cases, as, for example, in a normal solution of $K_3Fe(CN)_6$ in which the rate of grinding (58 mg.) is very much greater than any observed with the electrolytes listed in Table III. The formation of a surface layer of silver salt soluble with difficulty in the presence of oxygen may also influence the rate of grinding in certain cases.

The results obtained with copper were less characteristic; they are given in Table IV.

TABLE IV.

Electrolyte	M Mg
Water	10·0
KCl	14·5
KBr	13·5
KI	15·0
KCNS	17·5
Na_2S	32 9

The high rate of grinding of copper in the solution of Na_2S should be noted.

Realising the possible practical implications of the above experiments, the authors extended them to sintered tungsten carbide hard alloys.† An investigation with these alloys was interesting from two points of view. Firstly, their very heterogeneous structure made it appear likely that the electrochemical effect of solutions of electrolytes during grinding would be much greater than in the case of the comparatively pure metals previously used. Secondly, the practical value of discovering means of speeding up the grinding of these extremely hard materials is apparent. The experimental conditions in this investigation were similar to those in the previous experiments.

The majority of the experiments were carried out on specimens of "Pobedit," a tungsten carbide-cobalt alloy produced in the U.S.S.R. The specimens were in the shape of 40 mm. discs with a central hole of 15 mm. Glass and copper-grinding discs 50 mm. diameter were used. The abrasive was a carefully prepared emery powder. For each experiment 5 g. of emery were suspended in 5 ml. of water or solution of electrolyte. The rate of grinding was determined by weighing both the specimen and the grinding disc. Each experiment was continued for 30 mins.

Some of the results obtained (the mean of several determined) are given in Table V.

TABLE V.

Electrolyte.	Weight of Metal Ground Away in 30 mins. Mg
Water	40
$N.Fe_2(SO_4)_3$	344
$2N.CuSO_4$	1,203
$2N.AgNO_3$	1,174
$N.HgNO_3 + N.HNO_3$	1,522
$N.HNO_3$	115
Abrasive	30-min. emery.
Grinding disc	Glass.
Speed	74 r.p.m.
Pressure	240 g/cm$_3$.

In all the experiments a finely ground surface was obtained. The wear on the glass disc remained practically constant in all the experiments, irrespective of the nature of the electrolyte, amounting to about 600 mg. The very considerable increase in the grinding rate of the tungsten carbide alloy in the presence of solutions of electrolytes will be seen from the figures in Table V. The considerable effect of the $HgNO_3$ solution should be noted and compared with its effect on the rate of grinding of iron (Table I). It is probable that in the case of the tungsten carbide, only the cobalt becomes amalgamated. This would add to the electrochemical effect of the heterogeneous surface and would also facilitate the breaking out of the grains of tungsten carbide.

Experiments carried out in the presence of $CuSO_4$ solution showed that the effect of the electrolyte gradually decreased if the experiments were repeated with the same solution of $CuSO_4$. In three successive experiments with a solution of 1 g. equivalent of $CuSO_4$ per litre the rate of grinding was respectively 1,048, 467 and 27 mg. After the third experiment, all the Cu ions in the solution had become replaced by Co ions.

The rate of grinding both in water and $CuSO_4$ solution increased as the speed of rotation of the grinding disc was increased—e.g., in $2N.CuSO_4$ from 733 mg. at 74 r.p.m., to 1,592 mg. at 174 r.p.m. The rate of increase is approximately linear.

In the experiments in which the effect of the speed of rotation of the grinding disc was investigated, it was found that the rate of grinding of the glass disc was slightly

† A. G. Samartsev and V. P. Lavrov. *Zhurnal Tekhnicheskoy Fiziki.* VII, 1937, No. 9, pp. 926–930.

higher in the $CuSO_2$ solution than in water. This, however, was not due to an effect of the electrolyte on the glass, but to the large number of tungsten carbide grains which were present in the abrasive when grinding with $CuSO_4$.

The rate of grinding of the tungsten carbide alloy was also found to increase linearly with increase in pressure of the grinding disc, both when grinding in water and in $CuSO_4$ solution. Copper grinding discs were used for these experiments.

Finally, some experiments were made to study the influence of the grain size of the abrasive on the rate of grinding (Table VI).

TABLE VI.

Type of Abrasive and Grain Size.	Rate of Grinding in Water.	Rate of Grinding in $CuSO_4$.
7μ emery	11	150
20μ "	25	733
50μ "	55	1228
20μ quartz	3·6	250

It is not intended to present an appraisal of the practical value of the work which has been reviewed. Whatever this value may be, the subject of the investigation, and the light that has been shed on it, give rise to certain trends of thought which it may prove well worth while to pursue in theory and try out in practice.

Quite clearly, the main point brought out by the investigation is the valuable contribution that chemical reactions may make to the efficiency of machining operations. The energy which may be liberated in chemical reactions is well known, and, very broadly speaking, future work on chemical reactions in machining operations will have to concern itself first, with the choice of an appropriate reaction, and second, with its control and guidance, in order to achieve the desired result. The investigation which has been reviewed has dealt with only one fairly narrow aspect of the whole problem, but the results obtained are nevertheless of considerable importance.

For the sake of completeness, reference may be made in conclusion to the reaction between gases and surfaces being machined, and the effect of this reaction on the efficiency or the operation.

Taking the extreme case in which the results depend entirely on the use of gases, we have the well-known gas-cutting and surfacing processes in which the use of a tool in the generally accepted sense of the word is completely eliminated.

The influence of gases on the common machining operations does not appear to have been studied, but cannot be ruled out. The possible use of reactive gases, such as, for example, chlorine, to act as "lubricants" and facilitate machining operations, has recently been considered.‡ Here again, practical investigations are still lacking.

The advantages of using reactive gas under appropriate conditions is, however, demonstrated very well by some Russian work on the grinding of diamonds. It was found that this notoriously difficult and tedious operation could be remarkably speeded up with excellent results by working in an oxygen atmosphere at a temperature of about 600° C. It will be obvious that under those conditions the mechanical grinding away of the surface was assisted by the oxidation of the surface to carbon dioxide. The oxygen will have the same effect on the diamond dust abrasive used, and the question regarding the possibility of using other abrasives, such as, for example, aluminium oxide, may be considered. While useless under ordinary conditions, such alternative materials may well prove adequate under the modified conditions described.

‡ *Light Metals*, IV, March, 1941, No. 38, pp. 54–56.

A Note on the Tempering of Certain Alloy Steels

By BERNARD THOMAS, F.Inst.P., F.Inst.F.

WHEN the analysis of certain alloy steel forgings fall in the upper limits of the specification, it becomes necessary to temper accordingly at the full limits allowed. As quenching after tempering is a desirable feature to ensure good Izod impact figures, there is some risk involved in setting up a state of false, or skin, hardness which not only is misleading, but may interfere seriously with the physical properties.

A typical example was furnished recently, in the experience of the writer, by a steel to Specification 4S11.

TABLE I.
TYPICAL ANALYSIS OF A STEEL TO SPECIFICATION 4S11.

Carbon	0·30%
Manganese	0·65%
Nickel	3·46%
Chromium	0·68%
Molybdenum	0·22%

Quenched from 830° C. in oil and tempered initially at 620° C., a hardness figure of 3·40 mm. (321 Brinell) was obtained, which was outside the range required of 3·85–3·50 mm. Increased tempering temperature appeared the obvious solution and the full normal limit of 660° C. was employed, followed by the standard water quench. The figure now yielded was 3·30 mm. (341 Brinell), which was higher than that provided at 30° C. lower temperature. As the test-piece had, in both cases, been quenched promptly in water after tempering, it was obvious that at 660° C. the 4S11 material was becoming susceptible to the quenching effect despite the fact that 830° C. is laid down as being the quenching temperature.

Feeling that the "chilling" effect from 660° C. could not possibly penetrate to the core, a cut of $\frac{3}{16}$ in. was machined from the surface to reduce the diameter of the test-piece by $\frac{3}{8}$ in. A further Brinell test on the new surface now gave the figure of 3·60 mm. (285 Brinell) which fell inside the range and in consequence the T.P. was "pulled" to yield the physical properties shown in Table II.

TABLE II.
PHYSICAL PROPERTIES OF 4S11 TEST-BAR.

Ultimate stress	60·0 tons per sq. in.
Elongation	23·5%
Izod impact value	80/81/84 ft.-lb.
Brinell hardness	285

Not the least curious feature of the subject was that the Brinell readings were carried out with a 10 mm. ball under a 3,000 kilog. load. If a 1 mm. or 2 mm. ball with corresponding lower loads had been employed a "skin reading" would have been understandable, but one would not expect the "chilling" effect to have been such that the standard load of 3,000 kilogs. could not have penetrated.

It is suggested, therefore, in cases where the analysis of such steels be in the upper limits of the specification, causing high-tempering temperatures to be employed, that not too much attention be paid to apparently high Brinell readings on test-pieces without first investigating the underlying cause.

The foregoing remarks will apply even more particularly to forgings of small dimensions, the effect becoming more acute where testing is carried out with a machine of 30 or 120 kilog. load. The only recourse possible is to put on one side such forgings as appear to be too hard and subject subsequently to a check test using either a 750 or 3,000 kilog. load with 5 mm. or 10 mm. ball.

Such steels as are likely to give trouble of the nature outlined include the nickel chromes—4S11, S65 and S81, together with the non-corroding types S62 and S80.

PERSONAL.

Mr. Bernard Thomas, recently technical works manager of the Shillington Tool Co., Ltd., has been appointed managing director of Midland Heat Treatments, Ltd., of Wolverhampton.

The Silver Brazing of Brasses and Bronzes

By H. R. Brooker

The use of low melting point silver brazing alloys has been greatly extended in recent years in the production of assemblies built up of various copper alloys. The wide margin between the brazing temperature and the temperature at which the copper alloy may begin to suffer objectionable physical changes is an important factor contributing to this expansion, coupled with ease of jointing and speeding up in production rates which these brazing alloys make possible. In view of the progress made, this brief survey of developments in the silver brazing of brasses and bronzes is of particular interest.

THE silver brazing or, as it used to be called, silver soldering of brasses and bronzes has been carried out by a variety of industries for many years. This does not mean that the technique or the materials used in brazing such alloys has remained unchanged. In recent years particularly, the constant evolution of new copper alloys, each an attempt to improve upon this or that set of properties possessed by its forerunners, has produced a steady stream of problems for those engaged in brazing the new alloys.

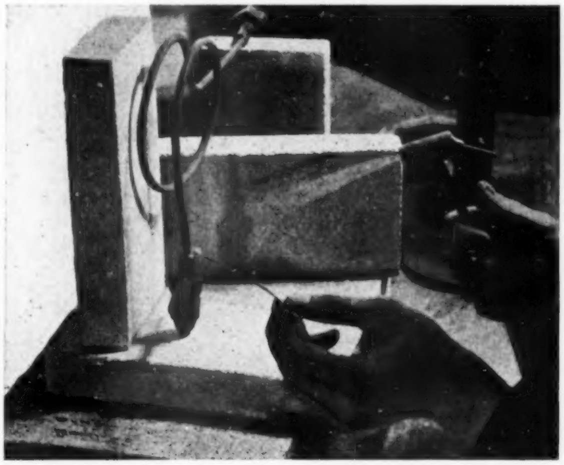
Under present conditions, silver brazing of cuprous alloys is practised to a far greater extent than ever before, There are several reasons for this expansion. One is that for once in a way, the best we can produce is only just good enough, and for this reason old prejudices and mistaken ideas about high costs have been swept aside. A most important factor in this growth of silver brazing is the increased proportions of unskilled and semi-skilled labour which are now being employed for production of assemblies built up by this method. By virtue of the wide margin between the brazing temperature and the temperature at which the copper alloy may begin to suffer objectionable physical changes, unskilled labour may usually be employed without harmful consequences to the work. Time has always represented money, but now it may well represent life itself. Therefore, the speeding up in production rates which is the normal result of substituting silver brazing for other allied processes is a highly desirable thing.

Enough has been written concerning the general field of silver brazing to make it unnecessary in this article to do more than give a brief survey of the developments in the processes which have enabled them to keep pace with the advances in cuprous alloy production.

Critical Temperatures

The avoidance of excessive annealing in metal adjacent to a brazed joint is a problem which is acute at a time when more nipples are being brazed to copper alloy tubes than at any previous time. The characteristic effects of such softening are reductions in tensile strength and fatigue resistance, the latter effect being particularly important where vibratory stresses have to be withstood. Annealing in such circumstances is controlled by time and temperature and the use of low melting point silver brazing alloys is the obvious corrective step. Not only is the temperature to which the metal is subjected kept as low as possible, but, due to the ease and speed with which strong, neat joints can be made, the metal is maintained at the elevated temperature for as short a time as is practicable.

Making brazed joints at as low a temperature and in as short a time as possible is also of importance in connection with some of the precipitation hardened copper alloys which are now in service. A normal characteristic of these alloys is that, after quenching from a high temperature, precipitation of the hardening constituent is effected by ageing for a given period at a lower temperature. In most cases, even a temperature of the order of 650° C. as required for silver brazing by means of the lowest melting point silver brazing alloy, "Easy-flo," is above the precipitation temperature, and if the alloy is maintained at this temperature for more than a very short period, loss in strength may occur. But



Low-temperature torch brazing of steel nipple to copper pipe.

it is often found that, by means of such a brazing alloy as "Easy-flo," joints can be made in so short a time that the physical condition of the metal is not appreciably changed.

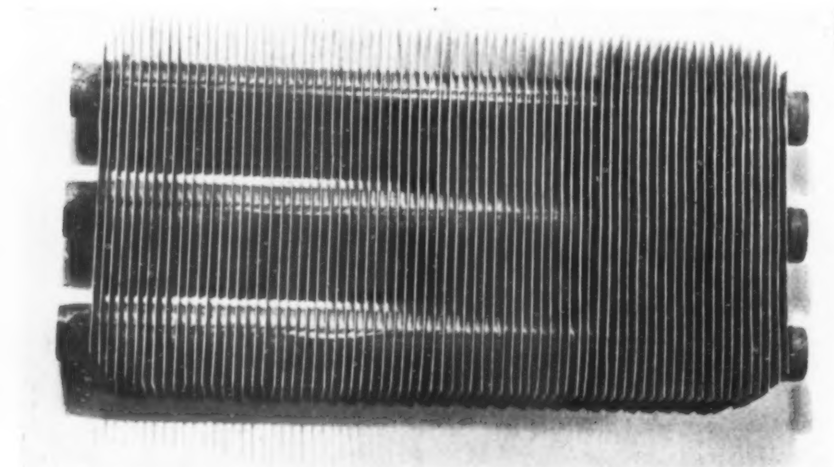
Refractory Oxides

Some of the high-strength copper alloys—aluminium brasses and bronzes, for instance—are difficult to braze by ordinary means, owing to the difficulty of properly "wetting" the metal surface with the brazing alloy. This is largely due to the rapid growth of thin but continuous oxide films, the reduction or solution of which cannot be achieved by borax-base fluxes. In conjunction with the lower melting silver brazing alloys, fluoroborate fluxes have been developed. These fluxes are extremely fluid and

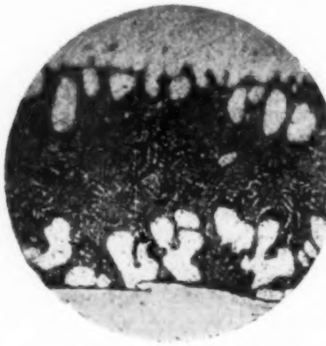
Brazing squirrel-cage rotors with "Silbralloy" at the works of Lancashire Dynamo and Crypto, Ltd.

active at temperatures below 600° C., and permit of full use being made of the low melting point of the most recent silver brazing alloy.

Although mechanical removal of oxide films prior to brazing cannot be dispensed with in the case of alloys containing high percentages of aluminium, the combination of a fluoroborate flux and a silver brazing alloy melting at the lower end of the temperature range in which the flux is active, does much to simplify the production of sound joints. The reason for this may be that the use of a comparatively low temperature slows down the rate of oxide film formation and the continuity of the insoluble alumina constituent in the film is broken by the rapid dissolution of the other metallic oxides by the fluoroborate flux.



Copper heat interchanger unit furnace brazed in air by "Silfos" by Main Water Heaters, Ltd.



Photomicrograph of "Easy-flo" in brass and steel. × 250.

Joining Dissimilar Metals

Specially developed silver brazing alloys of the silver-copper-zinc and silver-copper-cadmium-zinc type, in conjunction with the fluxes to which reference has already been made, have enabled manufacturers readily to braze together non-ferrous and ferrous parts. It is a comparatively simple matter now, for instance, to make joints which have a higher strength than the brass employed, between two such dissimilar metals as brass and 18–8 stainless steel. It is possible also, by means of correct fluxing and temperature control, to eliminate superficial oxidation of the stainless steel.

One of the requirements of a brazing alloy used for making joints between dissimilar metals is that it shall be sufficiently ductile to accommodate the stresses set up by differences in thermal expansion of the two metals. Certain of the high-silver brazing alloys possess the physical characteristics which are called for under these conditions.

Free-cutting Brasses

Many components which have to be machined from brass rod or tube have subsequently to be brazed. For the machining operations, free-cutting brass is obviously desirable, but, until recently, the B.S. specifications for such free-cutting brasses contained a note to the effect that such alloys could not be brazed.

When thinking in terms of spelter brazing, this provision was a necessary one on account of the small difference in the melting points of brazing spelters and free-cutting brasses. The result was that such components, in order to satisfy spelter brazing requirements, had to be made from alloys which were not the easiest to machine.

The development, however, of low-temperature silver brazing has permitted the removal from the B.S. specifications on free-cutting brasses of the restriction regarding brazing. The extra first cost of silver alloys as compared with brazing spelters has been more than off-set by the machining advantage gained and the speeding up of the brazing operation introduced by the use of silver alloys.

High Copper Brasses and Bronzes

For binary alloys containing only small percentages of metal other than copper, two brazing alloys of the silver-phosphorus-copper type are available. The alloys are "Sil-fos" and "Silbralloy." They are similar in characteristics, except that the former, by virtue of having the higher silver content, gives rather more ductile joints than does the latter. Both have melting points in the region of 700° C. and their phosphorus content enables sound joints to be made in certain circumstances without the use of flux. These silver brazing alloys have found several applications in the electrical industries by virtue of the fact that, although they have a fairly high electrical resistance in the cast state, closely fitted joints made with either brazing alloy in electrical conductors show a very low millivolt drop.

Unsound Castings

It frequently happens that castings in brass and bronze which are sound throughout the mass of the metal have small surface imperfections or blow-holes. Such defects, although probably quite unimportant so far as the physical characteristics of the casting are concerned, are unsightly, and may permit entrapment of corrosive plating solutions, giving rise to subsequent deterioration of the metal. The addition by gas-welding technique of metal of the same material as the casting to fill up these holes is often difficult, and probably involves very careful general heating and subsequent stress relieving by heat-treatment in order to avoid cracking and distortion of the casting.

The use of a silver brazing alloy, however, permits the filling of blow-holes at a much lower, and therefore safer, temperature. Moreover, there is such a wide range of colours available in silver brazing alloys that it is usually possible to select one which is almost undetectable after cleaning up.

Strength and Design

The industries employing silver brazing alloys on a large scale have realised that, in order to take full advantage of the facilities offered by the use of such materials, they must be prepared to design the joints in their assemblies to suit the characteristics of the alloys employed. Much information regarding such joint design has been collated compared with the data formerly available.

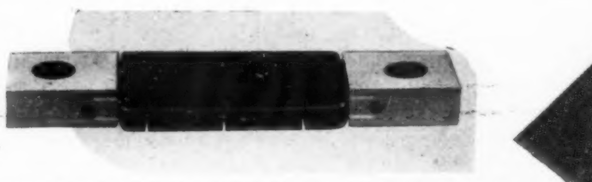
A point which is not always appreciated by those not familiar with silver brazing alloys is that, although joints

are made quickly at a comparatively low temperature, the strength of a sound silver-brazed joint frequently exceeds that of the metals being joined, particularly if the latter are non-ferrous alloys.

Design and strength of silver-brazed joints go hand-in-hand, and it is necessary to pay full attention to the first in order to obtain the second.

PROPERTIES OF MODERN SILVER BRAZING ALLOYS IN THE CAST CONDITION.

Alloy.	Composition.	Liquidus, ° C.	Solidus, ° C.	Brinell.	Max. Stress, Tons per Sq. In.
" Easy-Flo "	Ag : Cu : Cd : Zn	630	595	131	30
" D. 4 "	Ag : Cu : Zn : Cd	668	605	136	32
" Sil-Fos "	Ag : Cu : P	705	625	187	46
" Silbralloy "	Ag : Cu : P	694	638	195	35

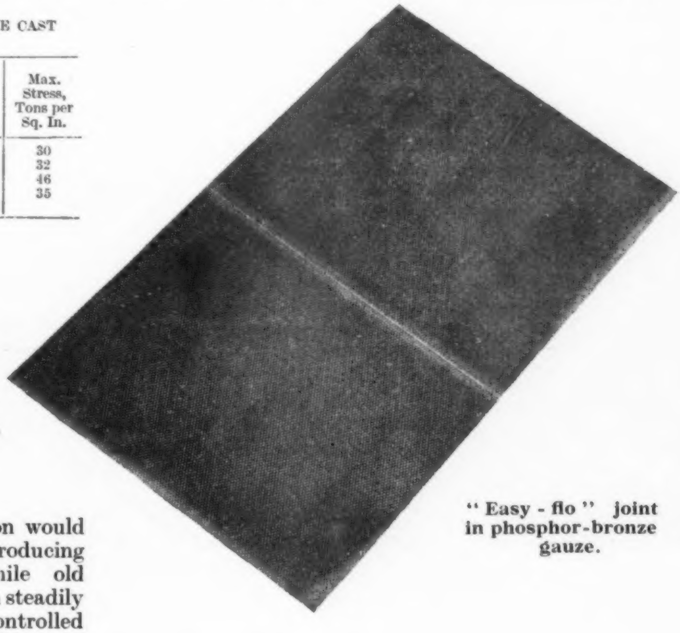


Copper and Eureka shunt joined with " Easy-flo" by Measuring Instruments (Pullin), Ltd.

Brazing Methods

The advances in silver brazing alloy production would have had little point had not the methods of producing sound joints improved proportionately. While old techniques, such as that of torch-brazing, have been steadily improved, new methods, such as brazing in controlled atmosphere furnaces and by electrical resistance heating, have been essential to the continued improvement of the process as a whole.

The author wishes to thank Messrs. Johnson, Matthey and Co., Ltd., for permission to publish this article, and those of the illustrations not otherwise acknowledged.



" Easy - flo " joint in phosphor-bronze gauze.

Methods of Stress Measurement by X-ray

THE relations between stresses and lattice constants and distances of interference lines respectively have been associated in connection with a uniform derivation of the various methods of stress measurement. The accuracy of the various methods especially has been investigated. The constants in the equations have been calculated in figures for measuring iron and steel in comparison with gold and silver. New radiographic values of elasticity coefficients of iron, developed by Möller and his collaborators,[1] have been considered in comparison with those values usually obtained by mechanical measurements. The former values contain an empirical reference to the influence of the elastic anisotropy which influences especially the determination of the zero values.

Elastic Anisotropy and Stress Measurement by X-rays

The equations of measuring stresses by X-rays have been developed on the theory of W. Voigt that all individual crystals forming the structure of the specimen under investigation suffer the same deformation as long as the stresses remain within the elastic range; but tests on specimens under known stresses showed deviations from the results obtained by the use of these formulas. This fact led to an investigation by Herrmann Möller and Gerhard Martin.[2] According to the theory of Reuss, all crystals forming the structure of a material are subjected to the same stress. This supposition was verified for the investigation of stresses measured by X-rays; but the comparison of the results obtained by calculations based on this theory of Reuss and by observation during tests, shows that this assumption also cannot be considered as a true indication of the facts. From the results of the tests by Möller and Martin new empirical values of the coefficients used in formulas for stress measurements by X-rays could be derived—i.e.,

Modulus of elasticity $E_r = 22{,}030$ kgms./sq. mm,
Poisson's ratio $v_r = 0{\cdot}374$,

the index r indicating in both cases that the values have been obtained from radiographic tests.

In future the authors intend to use these values when carrying out stress measurements on steels by X-rays, as they are convinced that they reflect the actual conditions better than those previously used, and from mechanical stress measurements derived values—

$$E_m = 21{,}000 \text{ kgms./sq. mm. and}$$
$$V_m = 0{\cdot}28$$

Finally, the influence of the new elasticity coefficients on the stress measurements was investigated. It was found that the influence exists for the derivation of the total main stress from one vertical exposure alone and for the determination of the zero value of the lattice constant in any case.

The Determination of Surface Stresses from a Single X-ray Photograph

The method of determining elastic surface stresses by X-rays can be considerably simplified, according to Möller and Neerfeld,[3] as the accuracy required is not too high. The position as well as the amount of the main stresses can be determined from a single oblique radiograph. The limits of error are, of course, wide in proportion because of the indistinctness of the interference lines. The method, therefore, is important in practice only if the main directions of stresses are known. If the angle between the direction of the rays and the vertical to the surface is $\psi = 45°$, and the angle between the projection of the direction of the rays to the surface and the main stresses is $\S = 45°$, these main stresses can be found from one radiograph with an accuracy of about $\pm$ 6 kgms./sq. mm.

The method has been checked by tests on specimens under known pressures in two planes at right angles to each other.

1 *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, vol. xxi, No. 20.

2 *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, vol. xxi, No. 17.

3 *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, vol. xxi, No. 19.

Classification of Copper and Copper Alloys—Part II

By H. J. Miller, M Sc.

(Metallurgist, Copper Development Association).

Copper-base alloys embrace such a large number of different compositions and their commercial nomenclature is so varied that the whole industry might well standardise on fewer compositions. Under present conditions, however, the method of classifying copper and its alloys, given by the author, will greatly assist engineers and designers in their task of specifying materials.

CONTINUING the various tables which were published in the last issue, the tables in the present section of this article are devoted to further copper alloys in various forms. The cast phosphor bronzes and gunmetals are given in Table X, while the aluminium bronzes for wrought and cast purposes are given in Table XI, copper-lead bearing alloys in Table XII, and wrought phosphor bronzes in Table XIII.

Again, it is important to point out that, while the data presented calls for little comment, it should be realised that modifications of compositions and properties are favoured by different producers, this especially being the case with the more complex brasses, where the number of alloying elements is considerable.

In the columns relating to mechanical properties, the suffix (A) refers to the annealed conditions, while the suffix (H) refers to the most fully work-hardened conditions which can usually be achieved in commercial production. The application of the heavy amounts of work required to achieve these latter properties are dependent to a large extent on the sectional dimensions.

TABLE X.

PHOSPHOR BRONZES AND GUNMETALS—CAST.

Description.	Composition (%).					Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Sn.	Zn.	Pb.	Other Elements.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % on $4\sqrt{A}$.	Diamond Pyramid Hardness.		
Gunmetal and Leaded Gunmetal. Admiralty Gunmetal	88	10	2	—	—	—	7	18–22	20	70–100	382/383	Admiralty metal is the standard composition for marine purposes, but the 87/9/3/1 alloy is frequently used in replacement.
87/9/3/1 Gunmetal	87	9	3	1	—	—	7	16–20	15	70–100	900/901	
87/7/3/3 Bronze	87	7	3	3	—	—	7	15–18	15	60–70	—	A popular material for cast fittings and is commonly termed electrical bronze.
85/5/5/5 Red Brass or Gunmetal.	85	5	5	5	—	—	6	12–16	15	60–70	897/898	An excellent casting alloy for valves and fittings for services at moderate pressure.
Phosphor Bronze "2 B8" phosphor Bronze	88	10 min.	—	—	0·5 min. P	Sand cast	8	12–20	4–15	80–100	2 B8	A standard phosphor bronze for bearing applications.
						Chill cast	10	16–20	2–5	100–130	2 B8	
Phosphor bronze—Sand cast.	90	10 max.	—	—	0·3 min. P		7	15–20	10–20	70–90	—	This is a less rigid phosphor bronze alloy and is more suitable for large castings for machine and other purposes where these are specified to be phosphor bronze.
Phosphor Bronze—(12% tin).	87·5	12	—	—	0·15 min. P	Sand cast	8	11–19	4–15	80–100	421 (for gears)	Although the specification quoted applies to gear blanks, this alloy is utilised for general bearings where its rigidity is of advantage.
						Chill cast	10	15–20	2–5	100–130	..	
						C'ntrif'g'l cast	12	17–21	2–7	100–300	..	
Bronze (14% tin)—Sand Cast	85	14	—	—	trace P	—	10	12–16	1–3	100–120	—	This material has little ductility and should only be used where freedom from distortion can be guaranteed and where its high hardness is desirable.
Bronze (18% tin).	81	18	—	—	Up to 1	—	10	10–12	1–3	—	—	Suitable for bearings subject to heavy compressive loads and employed for bridge and turntable bearings, etc.

TABLE X.—*Continued.*
PHOSPHOR BRONZES AND GUNMETALS—CAST.

Description.	Composition (%).					Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Sn.	Zn.	Pb.	Other Elements.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % on $3\sqrt{A}$.	Diamond Pyramid Hardness.		
Leaded Bronzes. 85/10/0/5 bronze.	85	10	—	5	—	—	6	12–15	5–15	70	960/961	This series of leaded bronzes of progressively increasing lead content, and hence increasing plasticity, is of considerable importance for medium- and low-duty bearings where some measure of plasticity is desired, where lubrication may be imperfect, or where the "mating" material is a soft steel which would be scored by harder materials.
80/10/0/10 bronze.	80	10	—	10	—	—	5	11–13	4–10	65	962/963	
76/9/0/15 bronze.	76	9	—	15	—	—	5	10–12	4–10	60	964/965	
"Plastic" bronze.	73	7	—	20	—	—	4	9–11	2–15	55	—	
"Plastic" bronze.	70	5	—	25	—	—	3	8–10	2–15	50	—	

TABLE XI.
ALUMINIUM BRONZES.

Description.	Composition (%).				Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Al.	Fe.	Other Elements.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % on $4\sqrt{A}$.	Diamond Pyramid Hardness.		
Cold-rolled strip and sheet; drawn tubes; other cold-worked forms.	Rem.	4–7	—	Up to 4 of Mn and/or Ni	4 (A)–20 (H)	8 (A)–38 (H)	25 (A)–50 (H)	4 (H)–70 (H)	75 (A)–220 (H)	—	Considerable advance has been made in tube uses, in which form the alloys may be obtained without great difficulty and show excellent corrosion resistance, and also resistance to oxidation on heating.
Hot-rolled plate and similar forms.	Rem.	7–10	—	Up to 2 of Fe, Mn, and Ni	6	10	25–32	40–50	80–120	—	
Rods and forged products— (*a*)	Rem.	9·5	—	—	8–10	12–20	33–40	20–40	160–200	DTD 160	These materials are fabricated by hot-working processes, including forging, and may be cold-worked to a limited extent only. The properties quoted are for the hot-worked condition. The materials are amenable to heat-treatment by quenching—which hardens, and subsequent tempering, which partially softens.
(*b*)	Rem.	10	—	1·25 Ni	10–15	20–30	40–45	18–30	200–240	DTD 135	
(*c*)	Rem.	10	1·5	2 Ni	10–15	20–30	38–45	18–30	180–225	DTD 164	
(*d*)	80	10	5	5 Ni	10–15	25–35	45–50	15–25	190–240	DTD 197	
Castings— (*a*)	Rem.	9	2·5	Ni and Mn optional up to 7·5	—	10–14	32–37	20–40	90–140	DTD 174A	This alloy is an excellent material for die-castings, but is also well known in the sand-cast state.
(*b*)	Rem.	10	4·5	4·5 Ni. Mn optional up to 2·5.	—	16–20	40–45	12–20	150–200	DTD 412	Available in die-cast and sand-cast forms.
(*c*)	Rem.	12	—	Additions of Fe, Ni, and Mn in amounts of	—	28–35	32–40	2–5	200–300	—	This hard series of alloys is of service where heavy compressive loads are involved; they show good "wear resistance."

TABLE XII.
COPPER-LEAD BEARINGS.

Descriptions.	Composition (%).			Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Pb.	Other Elements.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress. Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % om $4\sqrt{A}$.	Diamond Pyramid Hardness.		
80/20 Copper-Lead..	78	20	Up to 2 Sn, Ni and other elements.	—	—	approx. 9	—	45	—	Although the development of these alloys can be traced to the plastic bronzes, an entirely different technique of bearing manufacture is employed, usually involving bonding of the bearing alloy to steel shells.
70/30 Copper Lead..	69	30	0·6 Ag	—	—	approx. 9	—	30	DTD 274	
60/40 Copper Lead..	59	40	Up to 1 Ag and other elements.	—	—	approx. 8	—	30	—	

TABLE XIII.
PHOSPHOR BRONZES—WROUGHT

Description.	Composition (%). Cu.	Sn.	P.	Other Elements.	Typical Mechanical Properties. Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation %, on $4\sqrt{A}$.	Diamond Pyramid Hardness.	British Standards or other Specifications.	Remarks.
Strip and Sheet.											
Phosphor bronze—low tin.	96	3·75	0·1	—	4 (A)–25 (H)	7 (A)–40 (H)	22 (A)–48 (H)	5 (H)–65 (A)	60 (A)–210 (H)	407/1	The phosphor bronzes owe the majority of their applications to their good corrosion and corrosion fatigue properties, which account, for instance, for their uses as springs and instrument components. The usual material is B.S. 407/2, but for some conditions the harder material is preferred.
Phosphor bronze—ordinary quality.	94·5	5·25	0·1	—	4 (A)–30 (H)	8 (A)–45 (H)	23 (A)–52 (H)	5 (H)–65 (A)	65 (A)–230 (H)	407/2	
Phosphor bronze—high tin.	93	6·75	0·1	—	5 (A)–35 (H)	10 (A)–50 (H)	24 (A)–55 (H)	5 (H)–65 (A)	65 (A)–260 (H)	407/3	
Rod.											
Phosphor bronze—ordinary quality.	94	5·5	0·1	—	4 (A)–25 (H)	8 (A)–40 (H)	23 (A)–45 (H)	15 (H)–65 (A)	65 (A)	369 (hard)	Almost invariably used in a slightly work-hardened condition and a much favoured material for engineering components subject to friction.
High tin for bronze bearings.	91·5	8·25	0·25	—	15–25 (H)	25–35 (H)	30–40 (H)	20–40 (H)	120–140 (H)	DTD 265A (hard)	This is an improvement on the ordinary quality phosphor bronze rod for bearing purposes.
Wrought gunmetal	88	10	—	2 Zn	5 (A)–25 (H)	8 (A)–40 (H)	25 (A)–45 (H)	18 (H)–65 (A)	70 (A) 180 (H)	DTD 155 hard	This alloy is fabricated by special methods and in rod form its uses are for highly stressed parts, subject to corrosive conditions.
Wire.											
Phosphor bronze—ordinary quality.	94	5·75	0·1	—	—	—	24 (A)–60 (H)	3 (H)–55 (A)	—	384 (hard)	Almost iinvarably employed in the hardest conditions only for spring and similar components.
Fourdrinier wire quality.	92	8	—	—	—	—	25 (A)–65 (H)	3 (H)–55 (A)	—	—	This quality is used because of better corrosion and abrasion resistance.
Tubes.											
Phosphor bronze—ordinary quality.	94	5·75	0·1	—	—	—	24 (A)–40 (H)	10 (H)–60 (A)	—	T 52	
High tin bronze for bearings.	91·5	8·25	0·25	—	—	—	30–40 (H)	20–40 (H)	120–140 (H)	DTD 265A (hard)	See above for rods.

The Longitudinal Ridged Structure in the Tin Coating of Tinplate

A STRUCTURE in the coating of tinplate consisting of a series of straight or branched ridges lying approximately parallel to the direction of tinning is described by Dr. B. Chalmers and W. E. Hoare.* Observations of the tinning process and examination of finished tinplate show that :—

(*a*) The ridges arise from the runnels of tin which are established at the top pair of rolls in the grease pot and persist in similar positions on the sheet and on the rolls during the passage of the sheet;

(*b*) With thicker coatings the ridges are more widely spaced ; those, for example, on a plate carrying 14 lb. per basis box may be over ½ in. apart, whereas the spacing is about 0·1 in. on an ordinary coke-plate.

(*c*) Provided the coating thickness is reasonably constant, increased speed reduces the spacing of the ridges.

(*d*) The spacing increases as the temperature of tinning is raised.

(*e*) With thin coatings the ridges have a greater tendency to form " branches."

(*f*) Grease lines, when present, are almost exactly coincident with the ridges.

The unevenness of the tin coating is found quantitatively by examination of the variation of the coating thickness across the sheet at right-angles to the direction of tinning. The added thickness of tin in the ridge appears to be relatively independent of the mean coating thickness.

It was found that a similar ridge structure arises when other liquids are spread on solid surfaces by means of rollers ; this made it possible to carry out a number of experiments with a view to examining the phenomenon, using substances fluid at room temperature and, for convenience, on the surfaces of two rollers running idle. The most obvious characteristic of the ridged structure is the spacing of the ridges, and a series of experiments was also carried out to ascertain the effect on the spacing of variation of speed and distance apart of the rollers.

The experiments show that the ridged structure is produced when a rolling action takes place between two cylindrical surfaces, or one cylindrical and one plane surface, separated by a liquid which wets both surfaces forming a meniscus in the neighbourhood of the line of closest approach. The structure also appears when two plane surfaces inclined to each other at a small angle contain a liquid meniscus near the line of intersection of the two planes, and the angle between the planes is increased.

In cases where the liquid fails to wet one or both of the surfaces, different conditions are set up. The movement of the meniscus is not opposed by the fact that the liquid wets the surfaces ; in addition, the profile of the meniscus is convex instead of concave, and so pressure is exerted in such a direction that liquid moves towards the centre of the meniscus from one or both sides. This does not permit chance depressions of the surface to become stabilised.

It has been confirmed that the use of rollers not attacked and wetted by molten tin results in the suppression of the longitudinal ridged structure, and a pair of chromium-faced rollers[1] has been installed on an experimental tinning machine in the laboratories of the Tin Research Institute. Preliminary observations show that with a pair of non-wetting rollers fitted in place of the usual pair at the top of the grease pot, the longitudinal ridge structure is eliminated, with consequent improvement of the appearance and continuity of the coating.

* Iron and Steel Institute, September, 1941. (Advance Copy.)
1 British Patent No. 496,402.

Alloy Plating

Some Applications and Underlying Principles

A wide variety of different alloys are now commercially plated on a number of basis metals. Increasing commercial interest is being shown in this form of deposition, several advantages for which are cited by C. L. Faust, who briefly reviews some of the applications of alloy plating and discusses the underlying principles of the process.*

ALLOY deposition is entering a period of increasing commercial interest, and it shows great promise in engineering application, where, from a metallurgical point of view, there are outstanding possibilities. The metallurgist might well include co-deposition among his useful processes, just as he is beginning to include powder metallurgy. Valuable advantages have been found in electro-deposition of bearing metals, such as silver-lead, silver-cadmium, lead-tin, copper-graphite, tin graphite, and copper-lead alloys. Certain advantages result from alloy deposition in bearing manufacture :—

1. Thin liners can be produced with relatively little after-machining and scrap problem.
2. Preparation in a "cold-casting" process does not affect the backing material in heat-treatment or tempering.
3. Alloys can be made of metals difficult to alloy in any other way.
4. Unusually fine grain size and structural uniformity are obtained.

Sensitive high-temperature thermopiles; iron alloys having exceptional magnetic properties; alloy for electro-forming thin sheets; and alloy materials that can be electro-deposited for building up worn parts or for special surfacing have been proposed. Copper-zinc alloy of exact composition has for many years been deposited as a bonding layer for rubber coating of steel. Another application provides a silver-copper alloy for an undercoat for enamel. Intermediate alloy layers are deposited to improve subsequent nickel and chromium or other plates. Solder refining and manufacturing by electrodeposition have been done for many years.

An interesting process is the forming of alloys by heat-treating after deposition of different metals in individual layers. This, however, is not actually alloy deposition. Certainly, in the last few years, alloy deposition has emerged from the confines of the laboratory, where, apart from brass and gold alloy plating, the subject had resided many years as a curiosity. To-day, there are a number of instances where the desired alloy composition and properties are maintained in long use of the baths in the laboratory, pilot plant and production plant.

Success in alloy deposition depends on an empirical knowledge of the effect of the several variables on the plate deposition and the anode dissolution. Patience is required during development in order to find out what are the optimum ranges for operation. Once the proper bath has been found, the fine adjustment of conditions and their maintenance for control do not differ greatly from those for single metal deposition.

The cathode, and even anode process control, has been studied for numerous systems, and sufficient data has been accumulated to show the general procedure to be followed in securing alloy plates. It is confidently asserted that the future will see considerable developments in the application of alloy plating in: (1) Decorative finishing, because of bright plate, or of other physical and chemical properties of the plate; (2) protective finishing, based on the physical and chemical properties of the alloy plate and on its long life in certain environments; (3) engineering uses, such as electro-forming, manufacture of bearings, cladding of factory equipment, preparation of special alloys too costly to prepare by other than electro-plating methods, bonding layers, special surfacing of metals; (4) preparation of alloy powders.

Major interest in the development of alloy plating is expected in engineering applications.

Principles of Alloy Plating

The same principles that apply to single metal deposition apply to alloy deposition. The same few variables control both. In order to codeposit two or more metals, the several variables must be combined in a way that causes the several metals to have the same deposition potential. In an alloy plating bath the single electrode potentials, E^s, of the metals as given by Eq. (1), are generally fairly close together.

$$E^s = E^d - \frac{RT}{VF} ln\ a^{v+} \tag{1}$$

The equation refers to a static condition of reversible equilibrium. Since deposition usually occurs in an irreversible process, Eq. (1) cannot indicate the deposition potential which is a dynamic value associated with the discharge of cations at a definite rate.

The deposition potential, E^d, as given by the equation—

$$E^d = E^\circ - \frac{RT}{VF} ln\ a^{v+} + P \tag{2}$$

includes a term P. P equals or exceeds $(E^d - E^s)$. In both Eq. (1) and (2) the factor a^{v+} is the activity of the depositing cation in the film of plating bath at the cathode face. E° is the equilibrium electrode potential; P can be called a rate factor expressed as the extra potential required to keep the deposition going at the given speed. The rate of discharge is known to depend on the current density. Calculation of a metal deposition potential by Eq. (2) requires a knowledge of the values of a^{v+} and P for the given plating conditions, on which the values depend—i.e., current density, temperature, concentration and valence of all ions, ion mobility, pH, etc.

These variables influence the rate at which metal ions are brought to the cathode layer and the rate at which they are removed by deposition. Inasmuch as these same variables determine the ion concentration in the cathode liquor layer, they also influence the actual value of a^{v+}. Therefore a certain type of bath can be used for alloy plating, when for two metals, M_1 and M_2, the ion relationships in the liquor layer adjacent to the cathode are such that a_1^{v+} and P_1 have values relative to a_2^{v+} and P_2 during deposition, which offset the differences between E_1° and E_2°. Then both metals will deposit at the same deposition potential E^d.

No way has yet been found for directly measuring a^{v+} and P for the irreversible process of metal deposition. Although the Eq. (1) and (2) can be derived by several methods, neither the method nor the equation gives any information on the nature of the process occurring in the deposition reaction.

Fortunately, we can measure single electrode potentials and single metal deposition potentials under conditions where certain factors are known. This information can be used indirectly in alloy plating studies.

Those solutions of the metal salts in which the single electrode potentials E_1^s and E_2^s are quite close together, obviously indicate that ion activities of the two metals are nearly the same, which is one requirement of an alloy plating bath. However, the single electrode potentials

* Electrochemical Society, General Meeting, Chicago, October, 1941.

merely indicate what types of solutions should be used in measuring deposition potentials. In those baths where E_1^s and E_2^s are close together, E_1^d and E_2^d should be measured at several different current densities, temperatures, pH values, bath concentrations, etc.

Baths in which single metal deposition potentials can be made the same—i.e., $E^d_1 = E^d_2$, are possible alloy-plating baths. Fig. 1 shows a representative chart in which it is seen that, for a given bath and at certain current densities, the single deposition potentials for two metals M_1 and M_2 are the same.

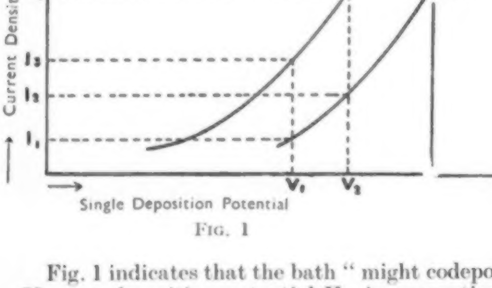


FIG. 1

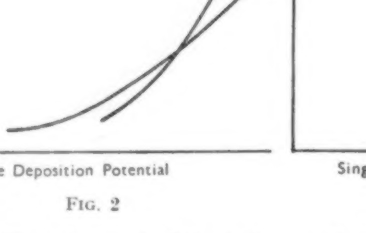


FIG. 2

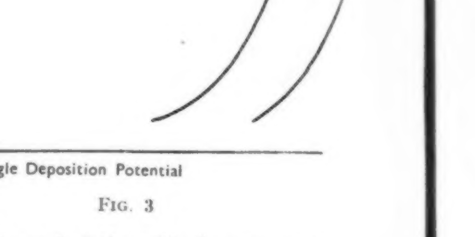


FIG. 3

Fig. 1 indicates that the bath " might codeposit " M_1 and M_2 at a deposition potential V_1, in proportional amounts equivalent to I_3 and I_1, and at V_2, proportionally equivalent to I_4 and I_2. The expression " might co-deposit " is used because controlling factors are independent. The M_1 and M_2 curves were determined separately, when only one metal was depositing. In this case the values for a_1^{v+}, P_1, a_2^{v+}, and P_2 were not influenced by the co-deposition of any other cations (assuming 100% current efficiency of deposition and, therefore, no hydrogen deposition).

If M_1 and M_2 are in the same bath, and the deposition potentials E_1^d and E_2^d are measured during co-deposition, the values quite likely would not equal V_1 and V_2 for corresponding single-plating conditions. When M_1 and M_2 are co-depositing from the same bath under conditions thought to be the same as assumed for Fig. 1, the actual relative deposition potentials might be found to exist as shown by Fig. 2, if some way were known for determining single deposition potentials during co-deposition. In extreme cases, depending on current densities and polarisation effects, Fig. 1 might even become Fig. 3.

Co-depositing metals apparently influence each other. When M_1^{v+} and M_2^{v+} are both present in the cathode film during co-deposition, a_1^{v+} and a_2^{v+} are probably different respectively from the relative values when the ions of only one metal are present in single deposition. Likewise, the polarisation factors influencing P_1 and P_2 for each metal relative to the other and to hydrogen are likely to differ in alloy and in single crystal deposition. Therefore, El. (2) and single deposition potential measurements are only of indirect use in alloy plating.

Single deposition studies might even show little possibility of alloy deposition with some metals in certain baths; for example, nickel and iron from cyanide or tungsten from alkaline baths, which, if tried in single deposition, would be discarded as unfavourable for alloy deposition. When these metals are in such " non-plating " baths containing other metals that can deposit out, the " unplatable " metal will co-deposit under certain conditions. For example, Cu-Ni, Cu-Fe, Cu-Zn-Ni, Cu-Ni-Fe, Ag-Ni, Au-Ni have been deposited from cyanide baths and tungsten alloys from alkaline solutions. No alloy plating prospect should be overlooked merely because one of the metals cannot be deposited singly from one or the other bath.

When depositing even one metal from aqueous solutions, we are always concerned with " alloy plating." At least, this is one way of considering the facts, since in single metal deposition the possible co-depositing cations are those of the metal and of hydrogen. It makes no difference whether most of the hydrogen discharged at the cathode escapes as gas. "Alloy " plating, as generally considered, merely changes this factual viewpoint to " hydrogen and two or more metals."

The value E^d in Eq. (2) is the decomposition potential when the term P has its minimum value. Hence, the decomposition potential is the minimum deposition potential that will cause continuous deposition of a metal, as far as plating is concerned. Metals that are to be co-deposited seldom have decomposition potentials that are close to each other in simple salt solutions. Approximately the same decomposition potentials are more likely to occur in solutions containing complex salts of the metals.

Parks and LeBaron[1] have empirically developed an equation that is interesting in the study of alloy deposition. The limiting concentration of the second metal in the bath at which pure second metal will deposit is shown as a function of the valences of the two metals, the difference in single deposition potentials, the equivalent weights of the co-depositing metals, and the cathode current density, where mono- and vi-valent metals are involved in acid baths.

$$l = \frac{aZ_1^2 - bZ_2^2}{Z_2^2 + cZ_1^2} \cdot \left(\sqrt{\frac{l}{N}}\right) \cdot \frac{E_L}{E_H} . log\ c.d. \quad (3)$$

also, $l = \frac{C_1}{C_2}$ where C_1 is the concentrarion of cation of lower cathode potential and C_2 that of the cation of the higher cathode potential at the limit of co-deposition.

Z_1 = valence of ions of lower cathode potential.
Z_2 = valence of ions of higher cathode potential.
N = difference in cathode potentials of the pure metals at the given *c.d.*
E_L = Eq. wt. of metal of lower cathode potential.
E_H = Eq. wt. of metal of higher cathode potential.
c.d. = cathode current density (milliamp./cm.^{2}).

a, *b* and *c* are constants which Parks and LeBaron empirically evaluated from data on several combinations of co-depositing metals. The equation accounts for the ratio of ion activities in co-deposition, since it includes the valence and concentration ratio, on which activities are dependent. The effect of other variables, not included, would be to influence the term N and the constants.

The previously used term " might co-deposit " in reference to two or more metals is too broad from a practical sense. The term should be narrowed down to " might co-deposit in acceptable form." Thus, Figs. 1 and 2 show possible co-deposition potentials, but these bear no relation

TABLE OF NOMENCLATURE.

E°	static or equilibrium electrode potential of a metal in contact with a solution containing ions of the metal at unit activity.
E^a	static or equilibrium electrode potential of a metal in contact with a solution containing ions of the metal at some activity state other than one.
R	gas constant expressed in joules.
T	temperature above absolute zero.
v	valence of ions of the metal.
F	Faraday, expressed in coulombs.
a	activity of the metal ions.
Ed	calculated deposition potential of a metal—i.e., the electrode potential obtained during current flow to deposit the metal continuously.
P	extra potential required over the static potential in order to maintain deposition at a given rate.
M	represents any metal to be deposited.
V_2 and V_2	represent measured deposition potentials of metals from solutions of unknown metal ion activity.
I	current density.

1 Parks and LeBaron. Trans. Electrochem. Soc. **69,** 599 (1936); **70,** 373 (1936); *J. Phys. Chem.* 42, 125 (1938).

per se to physical form of the plate. One frequently finds that at V_2, for example, or even at V_1, the limiting current density for sound plate of M_1 has been exceeded, although the limiting current density for alloy plate has not been. Co-deposition frequently has no practical value, unless addition agents can be used to improve the physical condition of the plate. Examples are found in silver-lead, nickel-zinc, and copper-tin plating. On the other hand, instances of the reverse are true—that is, acceptable plates are produced beyond the limits indicated in Figs. 1 and 2. In this case, co-deposition has raised the apparent limiting current density of one of the two metals. Examples are found in plating of cadmium-silver, bright nickel-zinc, copper-tin, and silver-lead alloys.

When problems of physical condition of plate arise, the alloy plated can turn to "tricks" known to all platers, such as use of addition agents, altering the pH, changing the degree of agitation, varying the bath temperature, etc. These are some of the reasons why each alloy plating problem is solved only by experiment. The optimum combination of the several variables and operation ranges are determined for each particular alloy.

By careful study of the literature bearing directly on a given metal combination or on other combinations containing one of the metals, probable alloy-plating baths can frequently be determined by a few experiments. Tedious measurements of deposition potential are then eliminated. In any case, the optimum bath composition must be developed empirically. After the conditions for co-deposition have been found, only the first step towards a commercial process is completed. Next the anode reactions and the effect of variation in the several factors must be studied. All the experimental developments should be made with as complete freedom from bath impurities as possible. Frequently alloy deposition baths have been discarded in preliminary work because of poor plates. The actual cause of the poor plates was the presence of small amounts of other metals or organic matter in the bath. After the pure solution experiments have led to a bath and reproducible operating conditions, then the tolerance for impurities should be studied.

The Flotation of Bauxite

A preliminary report deals with the results of a laboratory study of the benefication of Arkansas bauxite by flotation. It discusses the merits and limitations of this method of producing concentrates acceptable to the aluminium industry. General observations only are recorded, and this abstract briefly describes the investigation and gives the authors' summary and conclusions.

A LABORATORY study of the benefication of Askansas bauxite by flotation has been in progress for a considerable time, and although the investigation is not yet completed, a preliminary report* of the results on several typical bauxites shows the merits and limitations of flotation for the production of concentrates acceptable to the aluminium industry. The results obtained will undoubtedly be helpful to others engaged in this work and will probably lead to closer co-operation in carrying the problem to a successful conclusion.

Reference is made to recent papers by Litchfield[1], in which the benefication of bauxite is briefly considered. He states that the question of whether or not to improve the quality of the bauxite at the mines by some method of benefication depends on the cost of the process used, the percentage of merchantable material recovered as compared to the total quantity mined, and the relative improvement as to grade which has been accomplished. These factors in turn depend largely on the physical texture of the ore and the manner in which the impurities occur. Thus, certain types of American bauxites, consisting of nodules of hard high-grade material in a siliceous softer matrix, were subjected to relatively crude washing methods as early as 40 years ago; and there are certain types of bauxite in which the impurities are so intimately and stubbornly locked with the aluminium hydrate that they cannot be economically beneficated by any method thus far developed.

It is probable that as the relatively higher grade ores approach exhaustion, benefication will become increasingly important, and new and improved methods to raise the quality of the ore as mined will undoubtedly be developed. Considerable experimental work, with encouraging results, has already been carried out in the field of flotation, and it is not unlikely that much of the non-commercial reserves of America may, in the future, be profitably mined and prepared for market; particularly as the reserves of bauxite which are of a grade suitable to be mined and used without benefication are limited.

* J. B. Clemmer, B. H. Clemmons, and R. H. Stacy. Bureau of Mines Report of Investigation, 3586.
1 Lawrence Litchfield, Jr. "Bauxite." *Chem. Ind.* 1941, **48**, pp. 151-159, and 290-295.

Mineralogy of Bauxite

Bauxite was once thought to be a separate mineral with a composition of $Al_2O_3 : 2H_2O$, but this has since been disproved. The essential mineral present in most of the American bauxites is gibbsite ($Al_2O_3 : 3H_2O$), the trihydrate of alumina, which is easily dissolved in caustic-soda solutions, the basis of the Bayer process of recovering pure alumina from the aluminium ore that is still called bauxite. Diaspore ($Al_2O_3 : H_2O$), the monohydrate of alumina, is much less plentiful, though it occurs in some bauxites. When wet bauxites are dried near the mine for shipment, too high a temperature of drying tends to convert some of the gibbsite into the monohydrate diaspore, which is an undesirable result. Diaspore is much less easily dissolved in caustic-soda solutions of the improved Bayer process, and is largely unavailable to them. Bauxite was named from Baux, near Arles, France, and the correct French pronunciation is "bozite," whereas the common pronunciation, both in America and in this country is "bawksite." As there is no proof of the existence of a dihydrate of alumina as a mineral, bauxite has become merely a trade name for the gibbsite aluminium ore. The French bauxite consists mainly of another monohydrate mineral, bochmite, more easily soluble than diaspore.

Benefication of Bauxite

When used for the aluminium industry, American bauxite, whose essential mineral is gibbsite, should contain a minimum of silica and be relatively low in iron and titanium. Silica is most objectionable, as the Bayer process used for refining bauxite to yield alumina, which is subsequently electrolysed to give aluminium, is not applicable to high-silica material. The problem in benefication is therefore largely one of rejecting silica. Iron and titanium, when present in abnormal amounts, must also be rejected to obtain a product of the desired alumina content.

With many ores, iron and titanium can be rejected by magnetic separation or gravity concentration, but these methods are ineffective for rejection of silica, and other methods (such as classification and desliming or flotation) must be employed. The choice of the method or combination

of methods depend on the physical characteristics of mineralogical composition of the bauxite. Flotation, or a combination of flotation and gravity concentration, appears most promising for beneficating low-grade bauxite.

Scope of Investigation

The object of the investigation, on which only general observations are recorded in this report, was to determine the feasibility of treating low-grade bauxites by froth flotation to obtain concentrates containing 56% or more of alumina and less than 6% silica. Rejection of the silica, largely in the form of kaolin, was of primary concern, but rejection of the iron and titanium was also stressed. Various reagents were tested to develop a reagent charge applicable to a variety of ores of different mineralogic composition and permit flotation of gibbsite without the necessity of desliming.

Although particular attention was given to flotation, other methods of concentration were also investigated. Differential grinding and desliming tests were made on several ores when such treatment appeared feasible for the rejection of silica. Hydraulic classification and tabling tests of other bauxites were made to study the rejection of iron and titanium minerals and to obtain data for comparison of flotation and gravity concentration. A combination of methods, such as desliming and flotation, or table concentration and flotation, was used when necessary for the desired separation. Sink-and-float fractionations were made on a number of the samples. The data proved helpful in evaluating the results of subsequent flotation tests and also indicated the amenability of the ore to gravity-concentration methods.

Summary and Conclusions

The tests reported were of a preliminary nature to determine the feasibility of beneficating various bauxites by flotation. The results are encouraging from a metallurgical standpoint and demonstrate that many submarginal bauxites yield concentrates acceptable for the production of aluminium. The separation of gibbsite from silica does not appear unduly difficult; concentrates containing less than 6% silica have been obtained on all of the Arkansas samples tested, and many yield a product containing less than 3% silica with a favourable recovery of alumina. Flotation of gibbsite from ferric oxides and siderite presents more of a problem and will require further study. Although definite progress has been made in perfecting the separation of bauxites by flotation, much remains to be done before the ultimate is achieved. As experience is gained in flotation of bauxite, improved results should be obtained.

The ability to make a separation by flotation is no assurance, however, that processing may be economic. Many factors must be considered, and it would be premature to state that flotation would or would not be economic until further data can be obtained to support the preliminary tests. The samples of moderate silica content (7 to 12%) respond readily to flotation, and it seems likely that 80 to 85% of the hydrous alumina might be recovered under favourable conditions. Enough data have not been collected to indicate what recovery could be expected with high-silica materials. Undoubtedly, it would be less than with the low-silica bauxites and might be only 60 to 70% if high-grade concentrates are sought. As the silica content of the flotation feed increases, it becomes increasingly difficult to maintain both grade of concentrates and recovery.

Although flotation of bauxites appears promising, other methods of benefication should not be overlooked. With many bauxites, flotation would not be required. Careful grinding, followed by desliming, may suffice for the separation desired. Other ores may require gravity concentration to remove iron and titanium minerals. For many of the Arkansas samples tested, a combination of methods, such as gravity concentration and flotation, with or without desliming, seemed indicated. Flexibility of flow sheet will be essential for successful milling of a variety of bauxites of different grade and mineralogical composition.

Both cationic and anionic reagents have been tested, and the latter found more effective and controllable, especially from the standpoint of permitting pulp-modifying chemicals to be added to sharpen separation. Acidity of the bauxite, due to presence of soluble salts of iron, aluminium, magnesium and calcium must be reduced and "complexing" reagents like sodium metaphosphate or pyrophosphates added beyond threshold concentration for restraint of precipitation of hardness, but not in full stoichiometric equivalent to total hardness. Oleic acid and paper-mill fatty acid (toluol) are the most universally adaptable reagents for use as collectors of gibbsite, the main extractable mineral of the bauxite. The straight siliceous bauxite is efficiently concentrated by this set of reagents. Where siderite is present, step addition of the fatty acid permits prior floating of siderite before enough fatty acid is added to float bauxite. Also, in this latter case, pH must be raised above the range 7·0 to 8·0, which is most suitable for bauxite.

The laboratory study of the benefication of bauxites is being continued in an attempt to improve the separation of ores that have proved amenable and to develop a satisfactory method for treating those bauxites that heretofore have been difficult or nearly impossible to separate. Continuous flotation tests in the pilot plant will be made with representative bauxites to obtain comparative data on various reagents and determine their advantages and limitations on both the natural and deslimed materials.

The Iron and Steel Institute

THE autumn meeting of the above Institute will be held at 4, Grosvenor Gardens, London, S.W. 1, on November 25, 1941, commencing at 2-45 p.m. The proceedings will include the transaction of official business and discussion of the following papers :—

"Apparent Relations between Manganese and Segregation in Steel Ingots," by J. H. Whiteley. (Paper No. 8/1941, of the Heterogeneity of Steel Ingots Committee.)

"The Application of Spectrographic Methods to the Analysis of Segregates," by F. G. Barker, J. Convey, and J. H. Oldfield. (Paper No. 7/1941, of the Heterogeneity of Steel Ingots Committee.)

"The Ladle Cooling of Liquid Steel," by T. Land. (Paper No. 1/1941, of the Steel Castings Research Committee (submitted by Mr. D. A. Oliver).)

The following paper will be presented :—

"A Co-operative Investigation of the Factors Influencing the Durability of the Roofs of Basic Open-hearth Furnaces." A report by the Open-hearth Refractories Joint Panel (working under the aegis of the Iron and Steel Industrial Research Council and the Council of the British Refractories Research Association).

The Effect of varying the Silicon Content of Cast-Iron.

AN investigation undertaken with the object of observing the changes in the properties of cast-iron test bars containing total carbon 2·75%, 3·00%, 3·35% and 3·50%, when the silicon was gradually increased from 1·25% to 2·50%, is recorded by Seping.* The conclusions reached from the test results were: (1) There is an optimum silicon content for each carbon content at which the hardness values are of the same order for both light and heavy sections; (2) the tensile strength of an iron containing 3·50% total carbon decreases with increasing silicon content, but when the total carbon falls to 2·75% an increase in the silicon raises the tensile strength; and (3) the increase in the tensile strength amounts to about 5,000 lbs. per sq. in. for each 0·25% reduction in the total carbon.

* *Transactions of the American Foundrymen's Association*, 48, pp. 161-168.

Heavy Alloy: Its Production, Properties and Uses

The expression "Heavy Alloy" is only considered to be justifiable when the density of the alloy is greater than 15 grms./c.c., and for all practical purposes 16 grms./c.c. is taken as the lower limit. This alloy, which consists essentially of tungsten, is made by a powder metallurgical process; it has found many applications as an engineering material.

FOR many industrial purposes a heavy metal or alloy is required, and investigations have been in progress for some years with a view to the development of an alloy of high density and possessing considerable strength. The manufacture of such a heavy alloy has been successfully developed by General Electric Co., Ltd., the preparation, properties and industrial uses of which are described by G. H. S. Price, S. V. Williams, and C. J. O. Garrard.* This alloy, which is termed "Heavy Alloy," is 50% heavier than lead and has the tensile strength of a good quality steel.

TABLE I.
DENSITIES OF SOME METALS AND ALLOYS.

Elektron (Magnesium alloy)	1·8 grms./c.c.
Aluminium	2·7 ,,
Steel	7·8 ,,
Brass	8·4 ,,
Copper	8·9 ,,
Nickel	8/9 ,,
Molybdenum	10·0 ,,
Lead	11·4 ,,
HEAVY ALLOY	16·5—17·0 ,,
Tungsten	19·3 ,,
Gold	19·3 ,,
Platinum	21·5 ,,

The densities of a number of metals and alloys are given in Table I, from which it will be seen that of the common metals lead is the only one which is substantially heavier than the general engineering materials. Lead, with its excellent corrosion-resisting properties, is a very useful metal, but it is weak mechanically, and for this reason its use is limited to those applications where the stress is low. The precious metals, such as gold and platinum, are heavy metals, but their high price precludes their use for general engineering purposes. Tungsten, however, has a density equal to that of gold and is also relatively cheap. Because of its very high melting point (3,400° C.), pure tungsten, in the form of wire or sheet, is produced by a powder metallurgical process. A bar of pressed tungsten powder is sintered to a high temperature and subsequently worked by swaging, drawing and rolling to produce the metal in wire or sheet form. The sintering temperature required is in the region of 3,000° C., and this is obtained by passing an electric current (about 2,000 amps per $\frac{1}{16}$ sq. in.) through the bar. This method of sintering limits the size of bar that can be conveniently handled, and the production of fully dense tungsten in massive form is not a practical proposition, but an alloy consisting mainly of tungsten would still have a density considerably higher than lead and would be useful for the purpose of radium containers.

Attempts were first made to alloy tungsten with lead. The tungsten powder was mixed with sufficient lead powder to fill the interstices between the tungsten particles when the mixture was heated. It was found, however, that tungsten and lead do not wet each other, and homogeneous masses could not be produced. Experiments were subsequently made, using mixtures of tungsten powder with 5–10% nickel. On pressing and sintering at a moderate temperature, alloys were obtained with densities of the order of 16·5–17 grms./c.c., which is about 50% greater than lead. It was found that the addition of copper assisted production, and although the quantities of nickel and copper can be varied, the material, known as "Heavy Alloy," usually contains 90% tungsten, 7·5% nickel, and 2·5% copper. In addition to its high density, this alloy has a tensile strength comparable with good quality steel, and has consequently found application other than that for which it was originally intended.

* *G.E.C. Journ.*, vol. xi, pp. 223–237.

General Preparation

The requisite quantities of tungsten, nickel and copper powders, of a suitable degree of fineness, are thoroughly mixed together in the dry state. A small quantity of a suitable binder, such as a solution of wax in benzol, is then added, and the mixing continued until all the solvent has evaporated. The binder makes it possible to press coherent masses at much lower pressures than would otherwise be necessary, and for general purposes a pressure of from 5 to 10 tons per sq. in. is quite satisfactory.

The pressed pieces are supported on steel plates or refractory blocks and slowly heated to a temperature of approximately 1,000° C. in a muffle furnace. A reducing atmosphere has to be maintained in the furnace, and the initial stages must be carried out slowly. The second stage of the firing—namely, heating the pressings to a temperature at which a liquid phase is formed, is also done in a reducing atmosphere. During this second firing a linear shrinkage of up to 20% occurs on all dimensions, and this has to be allowed for in making the dies. When complicated shapes are required which cannot conveniently be pressed in one operation or when the quantity is not sufficient to justify the cost of a special die, it is usual to do the necessary shaping after the prefiring treatment.

Since the lowest value of density of practical interest is about 16 grms./c.c., only alloys containing more than 80% tungsten have been investigated in detail, and certain fundamental conclusions regarding the effect of composition on the density of alloys have been drawn which are independent of time and temperature of sintering, and these are summarised as follows:—

1. For a given percentage of tungsten, the maximum density is obtained when the ratio of nickel to copper is 3 : 1.
2. Alloys in which the percentage of copper exceeds that of nickel do not generally sinter satisfactorily, and are liable to be porous.
3. The alloys approach their theoretical densities more closely as the percentage of tungsten is reduced, but the theoretical values at the same time become less.

The density of any particular alloy is dependent on the purity of the metal powders used, and experiments have shown that the finer the tungsten powder, the lower the sintering temperature necessary to produce an alloy of high density and the more rapidly is the composition sintered.

When sintering, the appearance of the liquid phase sets a lower limit to the sintering temperature, and although the upper limit is not so critical, there are a number of factors which make it desirable that the sintering should be carried out as near to the critical temperature as possible. Connected with the temperature employed is the effect of time of sintering. It will be obvious that if the sintering temperature is not high enough for the liquid phase to be present, sintering will never be complete, however long the time. Once this critical temperature is reached sintering proceeds fairly rapidly, although with certain compositions

a considerable time is necessary in order to obtain the full density. The results obtained with a 93% tungsten alloy (theoretical density 17·8 grms./c.c.) sintered for various periods of times are given in Table II.

TABLE II.

EFFECT OF SINTERING TIME ON DENSITY.

Time of Sintering.	Density—Grms./c.c.
5 seconds	13·9
1 minute	14·1
5 minutes	15·0
¼ hour	16·3
½ hour	16·7
1 hour	17·2
6 hours	17·8

Not only is the time of sintering dependent on the temperature, but it is also very dependent on the composition of the alloy. Thus, if the alloy contains a larger proportion of the nickel-copper phase, sintering may be completed very much more rapidly, but this saving in time is largely offset by the possibility of distortion due to over-sintering.

Owing to the presence of the liquid phase during the sintering of Heavy Alloy, it is not practicable to reduce the quantity of tungsten to below 80%. In the normal way there is no object in doing this, since alloys with densities as high as possible are required, and for an alloy containing 80% the theoretical density is only 15·6 grms./c.c. There are, however, cases where alloys of some definite density (say, above those of the common engineering materials and below the standard Heavy Alloy range) are required, and it is in this connection that the addition of molybdenum has proved useful. Molybdenum, like tungsten, is a highly refractory metal, with a melting point of 2,450° C., but its density is appreciably less, being only 10·0 grms./c.c., as compared with 19·25 grms./c.c. for tungsten. Furthermore, molybdenum possesses all the properties necessary for the sintering mechanism to proceed, and it may thus be substituted for the tungsten in Heavy Alloy, the only effect being on the density of the finished product. Thus, the substitution of molybdenum for a part, or all, of the tungsten in Heavy Alloy has made it possible to prepare a complete range of sintered alloys with densities ranging from about 10 grms./c.c. up to 17 grms./c.c.

Theoretical Considerations

From the data given in the report, it appears that sintering of Heavy Alloy involves the following stages :—

Between 1,000° and 1,100° C. the nickel and copper particles become alloyed by diffusion, and some cohesion with the tungsten grains takes place. Very little further change occurs until the temperature reaches the melting point of the nickel-copper alloy, but above this temperature a very remarkable change takes place. The tungsten particles are rapidly dissolved by the liquid phase, but tungsten is reprecipitated on certain nuclei, which develop into the characteristic large, rounded grains. This process continues until all the original fine tungsten particles have disappeared, and are replaced by fairly uniform grains with diameters about 100 times those of the original particles. At the same time, all the remaining voids are eliminated.

That the tungsten grains grow by this process of solution and precipitation is confirmed by the behaviour of alloys containing copper only. Here there is no doubt of the presence of a liquid phase which wets the tungsten, but there is no solubility and no grain growth. With nickel only there is the necessary solubility, but unless the temperture is above 1,450° C., there is no liquid phase and the process of growth is slow and incomplete. When the ratio of nickel to copper is less than 1 to 1, the solubility is so much reduced that the process is again very slow.

Properties of Heavy Metal

The most important physical properties of Heavy Alloy are summarised in Table III. Thus the tensile strength and the yield-point of Heavy Alloy are comparable with those of a high-grade steel. The thermal conductivity is twice that of steel, but the coefficient of expansion is only about half. Heavy Alloy is very resistant to atmospheric corrosion. It may also be plated with any of the usual finishes, such as nickel, cadmium or chromium.

The strength of Heavy Alloy of any particular composition is a function of the density, and therefore increases as the sintering proceeds. The effect of sintering at the same temperature for various times on the density and strength of the resulting alloy is shown in Table IV.

TABLE III.

PHYSICAL PROPERTIES OF HEAVY ALLOY.

Tensile strength—tons per sq. in.	40
Yield point—tons per sq. in.	37
Elongation—% on 1 in.	4
Elastic modulus—lb. per sq. in.	32×10^6
Brinell hardness No.	250—290
Specific gravity	16·3—17·0
Weight—lb. per cub. in.	0·6
Coefficient of expansion	$5{\cdot}6 \times 10^{-6}$
Thermal conductivity—C.G.S. units	0·25
Specific resistance—ohm cm.$^{-3}$	$1{\cdot}16 \times 10^{-5}$
Electrical conductivity—ohm^{-1} cm^{-1}	$0{\cdot}86 \times 10^5$

TABLE IV.

EFFECT OF SINTERING TIME ON TENSILE STRENGTH.

Time at Sintering Temperature.	Density—Grms./c.c.	Ultimate Tensile Strength (Tons/sq. in.).
½ minute	12·6	18·8
¼ hour	13·9	25·8
½ hour	15·0	29·2
¾ hour	15·6	33·4
1½ hours	16·4	38·0
8 hours	16·8	41·5

Industrial Applications

Heavy Alloy was originally developed to meet the need for a high-density material in radium beam therapy. The use of large masses of radium necessitates the provision of adequate protection for the clinical and nursing staff, as well as for the patients. This protection is secured by heavy screening, but at the same time the actual container should be as small as possible if the radium is to be used efficiently, particularly in inaccessible positions.

The distinct advantage in the use of Heavy Alloy instead of lead has been established, and a number of applications was readily found for the material ; it has been adopted by most of the radium centres in Great Britain for radium containers and nose-pieces. These radium containers are frequently of complicated construction, being fitted, for example, with interchangeable nose-pieces suitable for different applications. In many cases the body of a container cannot be made from one piece of metal, and sections are required to be welded together.

Other examples of Heavy Alloy as a screening material include its use for screens in X-ray tubes, for cosmic ray absorption measurements, for the construction of surface applicators in radium treatment, and as a screening material in research work on radioactivity and radiographic examination of materials.

Much of this alloy is now used for the contacts of electrical circuit breakers. Its high-melting point and consequent resistance to burning by the electric arc have made it a powerful aid in designing breakers of very high capacity. A comparatively thin layer of the alloy, $\frac{3}{32}$ in. to $\frac{1}{4}$ in. thick, according to circumstances, was found to be sufficient to limit the burning to a tolerable degree. These tips are pressed and sintered to the required shape, and they are attached to the contact stems by electrical brazing or silver soldering. The stem and tip are then finished to size by grinding. Special shapes of contact are sometimes built up by brazing together flat plates.

This alloy is also being used for balancing the moving parts of machines of various kinds. The moment of inertia of a rotating body is directly proportional to its mass, thus it follows that a piece of this alloy is capable of storing twice as much energy as a piece of steel of the same size.

Dust-Explosion Hazards from Certain Powdered Metals

The possibility of dust explosion in plants handling carbonaceous dust is generally recognised, but the fact that metallic dusts may be explosive is not so readily accepted, yet metals such as iron, zinc, aluminium, and tin, which are commonly considered non-combustible, can burn with great rapidity and explosive violence when in a finely divided state. With the rapid growth of powder metallurgy, the need for protection against this hazard is of increasing importance, and a consideration of the subject is of interest.

EXPLOSIONS have occurred frequently enough in connection with the production and handling of carbonaceous dusts to be generally recognised, and safety codes or standards containing recommendations for protection against such explosions have been prepared for a number of industries where the hazard exists. Early investigators believed that only the carbonaceous dusts formed explosive mixtures with air, and it was not until the beginning of the present century that the explosiveness of certain metal and mineral dusts was recognised. It is only recently that metal powders other than aluminium and zinc have been produced in relatively large quantities. This increased production has been brought about by the rapid growth of powder metallurgy. To-day, more than thirty different types of metal powders are marketed, and many of them are handled in such large quantities that their production is referred to in thousands of tons. Experienced producers and users have recognised the hazard, and steps have been taken to provide necessary protection, but, as H. R. Brown* points out, these efforts to provide safe operating conditions and the necessity of guarding against ignition of such dust should be brought to the attention of new operators as additional plants are opened and other uses for metal powders are developed.

Established operators have submitted some samples of dust to testing laboratories to determine ignition temperatures, explosive limits of concentration, and the various factors that affect explosibility. However, many of the new powdered metals and alloys have not been tested to determine their relative inflammability, and for some of the other metal dusts only data based upon preliminary tests are available. It may be interesting to note that some of the metal powders tested have been classified as more explosive than the coal and other carbonaceous dusts that have been responsible for many serious explosions in the past. Present experience indicates that essentially the same factors which affect the inflammability of carbonaceous dusts must be considered in determining the explosive properties of metal powders.

Dust Ignition and Flame Propagation

The ease with which a dust cloud can be ignited and the rate at which flame will propagate through the cloud from the point of ignition depends largely on the size of the dust particles as well as on the density of the cloud and other conditions. Physicists have pointed out that in general (1) the finer the dust the more inflammable it is, (2) the finer the dust the smaller the flame or spark required to ignite it, and (3) the finer the dust the longer it remains in suspension in air, where it can be ignited most readily. There are many other factors, however, that must be considered in any study to determine the relative inflammability of a dust or the seriousness of a dust-explosion hazard in an industrial process. In testing carbonaceous materials, the percentage of ash and the amount of volatile matter may indicate the relative inflammability of the dust sample. Other factors that must be considered in virtually all dust-explosion tests are the shape of the dust particle and the moisture content; the ease with which the dust can be dispersed to form a cloud; the uniformity of size of particles forming the cloud; the density of the dust cloud; the uniformity of distribution or spacing of the particles; the presence of an ample supply of air or oxygen to support combustion; the size or nature of the ignition source; and the ease of oxidation of the dust particles.

The rate at which any substance will oxidise or burn depends on the surface exposed to the oxygen of the air, and when any solid substance disintegrates into dust its surface area is increased enormously. This increase in surface area can be illustrated by dividing a cube into smaller cubes. A 1-in. cube presents 6 sq. in. of surface, but if this solid block is divided into smaller cubes, each side measuring 1/100 in., there will be 1,000,000 cubes with a total exposed surface of 600 sq. in. A further reduction to 1/1,000-in. cubes would increase the surface to 6,000 sq. in. One investigator has estimated that 1 lb. of some of the finest metal powders has an expanded surface of about 220,000 sq. in.

Experiments show that the ignition temperature of some dusts drops rapidly as the size of the particle is reduced. In reporting the temperature of ignition of various dusts, Price and Brown[1] showed that a sample of cork dust, about 90% of which would pass through a 200-mesh screen, ignited at 1,080° C., while a sample that completely passed the 200-mesh screen could be ignited at 975° C. Similarly, a sample of starch with 80% passing a 200-mesh screen ignited at 1,035° C., while the sample that completely passed the screen could be ignited at 960° C. The ignition temperature of 150-mesh coal dust is 50° C. lower than that required to ignite 48-mesh samples. Although Beyersdorfer does not give the particle size, he reports[2] 485° C. as the ignition temperature of aluminium powder and 230° C. as the temperature at which fine aluminium grindings can be ignited.

In still air, the rate at which dust particles will settle is directly proportional to the density of the particles and the square of their radius. In industrial plants air currents may tend to keep small particles in suspension indefinitely and thus build up an explosive dust-and-air mixture, which presents a constant hazard. Experiments have shown that flame is propagated most readily in dust clouds in which the particles are small, of uniform size, and uniformly distributed. Under such conditions flame velocities of 2,000 ft. to 3,300 ft. a second have been measured, with indications of much higher velocities, probably greater than 6,000 ft. per second.

Metal-Powder Production

There are a number of different methods of producing metal powders, and the various processes are being improved from time to time. There are also variations in the several processes to allow the manufacture of different types of powder particularly suitable for special purposes. A list of the more important processes includes atomization, chemical precipitation, condensation, electrolytic deposition, machining, milling, and reduction. Except where the powder is produced or handled in dry form, there is no dust-explosion hazard in connection with the manufacturing operation.

* Extracted from the Report of Investigations 3577 of the U.S. Bureau of Mines.

1 Price, D. J., and Brown, H. R. "Dust Explosions." National Fire Protection Association, Boston, Mass., 1922, pp. 14–15, Table 1.

2 Beyersdorfer, "Uber den Begriff Feurgefährlichkeit". Zeitschr. tech. Physik, vol. 9, No. 1, 1928, pp. 17–19.

In the atomizing process the molten metal is forced through an orifice or nozzle, where it is struck by a jet of steam or compressed air or gas ; and as the metal solidifies in the form of fine powder, it is carried along with the air or gas stream to the collecting equipment. Explosive concentrations generally are present both in the ducts that carry the air and dust stream and in the dust collector.

Both dust- and gas-explosion hazards are present in the condensation process, which is used principally in the production of zinc and lead powders. The vapourised metal is reduced in an atmosphere of carbon monoxide and passed through a condenser. The rate of cooling determines the size and type of powder produced.

Machining is the process generally employed to produce magnesium powder, because of the difficulty experienced in preventing dust ignitions or explosions in other processes. Machining may be described as a large-scale or mechanised filing or cutting process, and the explosion hazard exists wherever quantities of the dust or powder produced are in suspension in air during preparation or handling.

Probably the most widely used method of producing metal powders is the milling process. The generally accepted term includes the production of powder in stamps, crushers, rolls, ball, bar, and disc mills, attrition mills, eddy mills, and jet pulverisers. In the last two types of equipment, air currents are employed in the grinding operation, and in all of the other types there is enough air movement to create dust clouds within or around the milling equipment during normal operation.

Two methods of milling designed to reduce the explosion hazard have been developed. One method, known as the Hall process, provides for the mixing of a liquid with the material entering the mill to form a slurry or paste, and thus eliminate dust ignitions within the mill. The explosion hazard is still present to some extent if it is necessary to dry or further condition the product after milling. The other method, known as the Hametag process, employs a stream of inert gas to carry the powder away from the mill as it is produced. The purpose is to prevent both oxidation and explosions. Fairly effective protection against explosions can be obtained in certain instances where an inert gas can be found that is effective in preventing ignition of the powders being produced and can be used to carry the material to the collectors or separators.

Metal powders are produced in a wide range of sizes, and different processes produce particles of different shapes. Certain types and sizes are better suited than others for particular uses. For instance, a flaked powder is desired for making aluminium paint, while angular particles are better for some forms of powder metallurgy. Very fine particles are necessary for making inks used for fine surface printing, decorating, or lining ; and here, again, flaked powders produce better leafing or coverage. Although very coarsely divided, metal in the form of shot sometimes is referred to as powder, it seems desirable, at least in discussing explosion hazards, to include only the commonly marketed sizes that may be ignited as a dust cloud. Under such classification the particle size of dusts considered explosive would extend from the 30-mesh magnesium used in pyrotechnics to the 400-mesh and finer bronzing powders used in high-grade printing inks. Some of these finer powders are reported to be about 0·4 micron thick.

In connection with metal-powder production, screening and packaging operations constitute dust-ignition hazards similar to those in other dusty industries employing the same type of equipment. Screens, bolters, sifters, reels, dust collectors, and similar machinery are required to make the necessary size separations, and generally some dust clouds are formed in or around packaging machinery.

Powder Metallurgy

The present stage of development of the fabrication process in which the metal powders, either singly or mixed, are pressed to the desired shape apparently presents a limited explosion or dust-ignition hazard. Hydraulic toggle, cam, and other types of presses may be employed, provided they can produce the necessary pressure. The pressure used ranges from a few tons to more than 100 tons per sq. in. The die parts are of hardened tool steel. The swagings now being produced are generally small, and the powder required for the individual pressings may weigh only a few ounces. However, pieces weighing 40 lb. or more have been produced, and large quantities of powder may be stored in the hoppers or bins of the automatic presses, from which it is fed in the desired amount to the die or mould. The ignition hazard is present while a bin or hopper is being filled with the powder or when failure of the feeding mechanism or spills create a dust cloud around the press.

Following the pressing operation, the parts are sintered or heat-treated for a short time. Because the material is no longer in powdered form, there is no dust explosion hazard in this operation. Some attention has been given to the possibility of eliminating this step in the process by hot pressing. Additional sources of ignition may be introduced in providing for hot pressing, and exceptional care will be necessary to prevent the metal powders that ignite at relatively low temperatures from coming in contact with highly heated parts of the press while they are in the form of a cloud.

Inflammability of Metal Powders

Aluminium powder has been produced in large quantities for many years. Increased use of aluminium paint stimulated production of the powder, and a number of serious explosions in connection with the production of the powder directed attention to the hazard of dust ignitions. Extensive laboratory tests have been made to determine the ignition temperature, limits of concentration, and other factors that would indicate the extent of the hazard and aid in the development of protective measures. Ignition has been reported at temperatures as low as 230° C., and references have been made by investigators to ignitions of dust clouds by glowers, induction-coil sparks, electric arcs, and mechanically produced heat. It is known that sparks from a piece of steel in contact with a grinding wheel can ignite a cloud of aluminium powder.

Research to determine the inflammable and explosive properties of other metal powders has been quite limited, and there is a paucity of data on the subject in published material. A number of tests have been made in Bureau of Mines laboratories at the request of producers or users of certain types of metal powders to determine their relative inflammability. These tests are designed to indicate whether the material is more or less explosive than coal dust, comparison being based upon the amount of inert dust that must be added to suppress ignition. The dusts so tested include several types of iron powder, several types of magnesium powder, zinc powder, and tin powder. All of these dusts were found to be explosive. Ignitions were obtained by blowing samples of dust into a furnace operated at temperatures ranging from 425° C. to 660° C., and by using an induction-coil spark as the source of ignition in a tube through which the dust was blown. The amount of inert material it was necessary to add to some of the samples to suppress ignition ran as high as 97·5%. Research will be necessary to determine the possibility of initiating ignitions by discharges of static electricity and to determine the hazard due to accumulation of electrical charges on the dust particles. As Gibbs[3] points out, in his reference to the work of Rudge, nearly all dusts become electrically charged when they are blown about in the air ; and as the charge resides upon the surface, the capacity of the dust is proportional to the total surface area. As previously pointed out, the finer the dust the greater the surface area, and therefore the greater the charge. In the table developed by Rudge, after testing nearly 200 different dust samples the character of the charge detected on different dusts is indicated, and it is interesting to note that the charge,

3 Gibbs, W. E. "The Dust Hazard in Industry." London, 1925, 168 pp.

found on aluminium, iron, magnesium, tin and zinc was negative in each instance. In his report on these tests,[4] it is pointed out that although many exceptions were noted it seemed to be fairly well established that (1) non-metallic elements give positively charged clouds when the dust is blown into suspension, and (2) metallic elements give negatively charged clouds when finely divided material is blown into suspension in air. Further research to determine the possible effect of the electrical charge present on duts particles in determining their explosiveness would seem to be warranted.

Protection Against Explosions

At this time it is difficult to make specific recommendations for providing protection against ignitions of metal powders, because, as previously pointed out, very little information is available on the factors that affect the explosibility of such materials. It can be assumed, however, that in general the safety codes developed for protection against dust explosions in other industries will be applicable in plants handling the metal powders used in powder metallurgy. Where it is not possible to provide absolute protection against dust ignitions owing to lack of knowledge concerning the inflammability of the product or because of necessary manufacturing conditions, some degree of protection can be provided that will greatly minimise the results of such ignitions and reduce the hazard to life and property. A discussion on the release of explosion pressure through properly proportioned and properly located vents[5] and two safety codes contain a number of recommendations for providing protection against dust explosions. The principal ones may be summarised as follows :—

1. Segregate hazardous processes in small, detached buildings or separate units, with fire walls and fire doors.
2. Provide vents, such as light roofs or large hinged window areas designed in the proper proportion, to release explosion pressure without structural damage.
3. Maintain equipment as nearly dust-tight as possible, and provide for frequent cleaning to prevent accumulation of dust at points where it may be thrown into suspension to form a cloud.
4. Eliminate all possible sources of ignition by using :
   (a) Electrical equipment approved for such locations
   (b) Indirect heating to prevent dust collecting on heated surfaces.
   (c) Ground connections on all equipment to remove static electricity.
5. Use inert gas to prevent dust ignitions wherever feasible.
6. Use conveying, collecting, processing, and cleaning equipment designed to perform its function with no possibility of producing metallic sparks or frictional heat capable of igniting the powder being handled.
7. Provide fire-fighting facilities of the type found best adapted to the particular needs of the plant.

It should be noted that water and ordinary types of fire extinguishers are not effective on metal-powder fires, and in many instances their use will intensify the fire. They should be rigidly excluded from sections of the plant where their use by inexperienced persons would be dangerous. Disturbance of quietly burning powder by hose streams or other means may cause a serious explosion. Dry sand, talc, rock dust, and similar material have been used to smother small fires in metal powder, but fine graphite is much more effective and is now generally recommended. A special fire-extinguishing powder has been developed for use on magnesium fires. All such inert substances must be applied carefully to avoid any disturbance of the burning material likely to throw it into the air, and the use of this method should be attempted only by persons familiar with the hazard. No satisfactory method of extinguishing metal-powder fires too large to be covered with powder is now known, and experienced operators usually prefer to seal a fire in the unit in which it started and permit it to burn itself out.

Conclusion

Powder metallurgy is an industry in which at present the art is in advance of the science, but, as developments continue, additional data on the properties of the different powders no doubt will be available. Our present knowledge of the factors affecting the explosiveness of the dusts is likewise limited, but the simple fact that the dusts are explosive, as shown in preliminary tests, should be justification enough for the adoption of all known precautions to prevent ignitions wherever such dusts or powders are produced, processed, or handled. Producers and users of metal powders are urged to co-operate in making available to the industry experiences or data that will contribute to the development of safe practices for explosion and fire protection and thus eliminate or reduce this hazard to life and property.

4 Rudge, W. A. Douglas. "On the Electrification Associated with Dust Clouds." *Phil. Mag.*, ser. 6, vol. 25, April, 1913, pp. 481–494.
5 Brown, Hylton R., and Hanson, Richard L. "Venting Dust Explosions." *Nat. Fire Protec. Assoc. Quarterly*, vol. 26, April, 1933, pp. 328–341.

Indium and Other Elements in Age-Hardening Aluminium Alloys

INDIUM has recently become available in sufficient quantities to be of commercial interest, with the result that some researches on its possible use as an alloying element have been, and are still being conducted. The results obtained from one of these researches dealing with the effect of indium on heat-treatable aluminium alloys has been investigated by W. H. Fraenkel,* who has shown that small amounts of indium have a decided influence on the age-hardenability of those alloys.

All the alloys in this investigation were prepared from metals of commercial purity, conductivity aluminium wire-bar copper, conductivity manganese and pure indium, except for small amounts of silicon (0·15%) and iron (0·30%), the resulting alloys were comparatively pure. The addition of indium to aluminium base alloys was easily accomplished and vertical castings about 0·4 in. thick were made in a preheated mould. These castings were hot-rolled to about 0·2 in., and specimens of the rolled sheets were solution-treated at 500° C., quenched in cold water, and the Brinell hardness determined until the hardness became constant. Some alloys were aged at room temperature and others at 120° to 150° C. Indium alloys containing magnesium were somewhat more difficult to roll than the others.

Alloys of the duralumin type, 4% copper, 0·5% manganese, which age at room temperature did not become harder with the addition of 0·1% of indium, although the rate of hardening was considerably lowered, and the same applied to an alloy containing 4% copper, 1% manganese, 0·5% magnesium without and with 0·13% of indium. Alloys without magnesium showed a marked increase in hardness with additions of 0·05% and 0·1 to 0·2% of indium, the influence of indium being greater on alloys containing only copper. Manganese additions to aluminium-copper-indium alloys decreased the hardening effect of indium.

The investigation was further extended by replacing indium with neighbouring metals in the periodic table, such as silver, cadmium, tin, antimony, tellurium and thallium, and as the addition of indium was most pronounced on aluminium alloys containing about 4% copper, 0·1% of each of the above elements was added to this alloy. The metals cadmium and tin increased the hardness

* *Metal and Alloys.* 1941, vol. 14, No. 2, pp. 168–169.

in a similar manner to indium, antimony had only a very small influence, tellurium decreased the rate of hardening, as did thallium, while the influence of silver was small and could just be observed. In these experiments the hardnesses were determined immediately after quenching, after one day at room temperature, and then after ageing at 140° C.

As the investigation was only confined to hardness tests, the data obtained did not allow of theoretical considerations being drawn. Aluminium alloys of the same hardness as those experimented with are already known, but they contain more copper or manganese or other elements which produce greater hardness in the quenched condition. In the alloys experimented with, the hardness after quenching is low, allowing easy deformation by mechanical means. The increase in hardness during ageing is remarkably high, and this fact, as well as the other that hardening takes place at a slower rate in the duralumin type of alloys and at a faster rate in alloys without magnesium may be of technical interest.

Annealing Nickel-Chromium Steel Forgings

By Bernard Thomas, F.Inst.P., F.Inst.F.

The annealing of the nickel-chromium forging steels is usually advisable in order to facilitate working and subsequent machining, and experience gained in the treatment of a range of these steels may assist in overcoming difficulties that they sometimes present.

CERTAIN of the nickel-chromium steel specifications entail that the forgings be delivered to the customers in the softened condition, while others, such as S65, may so nearly approach air-hardening properties that softening is advisable if much machining is necessary. The object of these notes is to offer experience gained in the execution of such work with a view to guiding others who may be encountering difficulties.

2S28 and S82 are those steels which are called for in the softened condition, while 4S11, S65 and 2S81, while not stipulated to be annealed, are, on occasion, subjected to that process in order to reduce machining time. Most users are familiar with the analyses involved, but to refresh the memory they are reproduced in Table I. Only those elements which influence hardening properties are given.

Specification 2S28.—Dealing first with the steels which are specified to be softened, the 2S28 is easily the more difficult. Ostensibly a gear steel, it is capable of hardening after heating to 820° C. and allowing to cool in still air. Stresses are relieved by a low temperature of 230°–250° C., and after such treatment the ultimate stress should not be less than 100 tons per sq. in., with a Brinell hardness of 444 (2·90 mm.) minimum.

TABLE I.
TYPICAL ANALYSES OF NICKEL-CHROMIUM STEELS.

Specification.	C	Mn	Ni	Cr	Mo
2S28	0·28	0·26	4·26	1·28	0·23
S82	0·16	0·38	4·36	1·19	0·11
4S11	0·30	0·65	3·46	0·68	0·22
S65	0·27	0·50	2·94	1·28	0·27
2S81	0·31	0·62	3·63	1·04	0·23

With such hardening propensities, it is not surprising that as produced in the as-forged condition forgings should have hardnesses ranging from 2·80–3·20 mm. (363–477 Brinell), thus necessitating softening to facilitate machining.

No temperature is laid down for the softening process, but experience shows that 650° C. yields the most suitable figures. With a further 170° C. available before the hardening temperature is reached, one might imagine that somewhere between 700° and 750° C. would be more likely to yield results; actually, however, this range of temperature usually produces forgings up to 3·40 mm. (321 Brinell), whereas 650° C. on the same cast of steel would normally return 3·65 mm. (277 Brinell as the maximum hardness, which conforms very favourably with specification demands of 3·60 mm. maximum or 285 Brinell.

Soaking time is important. A well insulated furnace should be employed, and after the full charge has reached the necessary temperature at least 5 hours' soak should be allowed on an average before cooling down in the closed furnace. The full annealing cycle will then occupy 30–40 hours on loads of approximately 5 tons.

Specification S82.—This is a case-hardening steel, and is therefore lower in carbon than other nickel-chromium types. Actually, apart from the carbon content, the remaining elements are practically identical with those in 2S28. With the lower percentage of carbon, the risk of hardening up from the forging temperatures is much reduced, although figures up to 3·40 mm. (321 Brinell) are possible, causing it to be necessary to soften to conform to the 3·65 mm. (277 Brinell) limit specified.

More scope with temperatures is permissible with 0·18% maximum carbon, and consequently 700° C. has been found to yield the best average results. Typical average hardness ranges in forgings dealt with at this temperature are 3·80–4·10 mm. (217–255 Brinell), which complies nicely with requirements.

Soaking time should again be not less than 5 hours, although in this instance the furnace may be discharged at a rather higher temperature than with 2S28, thus reducing somewhat the total time for the cycle.

Specifications S65, 4S11 and 2S81.—As explained previously, while the specifications do not call for the above types to be softened after forging, certain customers prefer it, particularly on large forgings. S65, with its potentially higher chromium content, is usually more likely to require annealing than the others, while S81, with the high physical properties, is not employed for forging purposes to anything like the same extent.

The specifications stipulate 660° C. as the maximum permissible tempering temperature for 4S11, 600° C. for S65 and 650° C. for 2S81. As all these types should nominally be supplied in the fully heat-treated state, it is only logical to assume that the employment of the respective temperatures should be sufficient to ensure a condition suitable for machining. While this is largely so in the majority of cases, there can be no doubt that a thorough soak at 650° C., followed by slow cooling, is more beneficial than a shorter period at similar temperature followed by oil or water quenching. Consequently, it is at 650° C. that forgings of the three types mentioned are soaked, and satisfactory figures are usually obtained.

The Brinell hardness limits of S65 were originally 3·55–3·40 mm. (293–321 hardness), but concession has been granted extending the harder figure to 3·30 mm., making now the full range 3·55–3·30 mm. (293–341 hardness) which same figures obtain for 2S81. Annealing at 650° C. and slow cooling will yield on both types a typical hardness range of 4·00–3·70 mm. (229–269 hardness) which satisfies most demands.

As regards the 4S11, less difficulty is presented by reason of the lower chromium content, which permits discharge from furnaces at an earlier stage than those steels containing a higher percentage of the element. With reasonable care a hardness range of 4·20–3·90 mm. (207–241 hardness) can be obtained with ease.

Reviews of Current Literature

The Physical Examination of Metals

VOL. 2.—ELECTRICAL METHODS.*

IN this volume is given an account of methods of examination classified as electrical and depending on the movement of electrons in metals. These electrical methods are dealt with in eight comprehensive chapters, illustrated by eight plates, and supplemented by two appendices.

Magnetism which is set up by the motion of electrons, either by movement or flow, is reviewed in relation to metals, consideration being given to methods specially designed for particular purposes, including the measurement of magnetic properties by induction and thermomagnetic methods. The detection of discontinuities and irregularities, the measurement of mechanical properties, and the measurement of sheet or foil or of coating thicknesses by such methods are discussed. The electrical resistance of metals, which is easily measured, and which yields much evidence, both direct and indirect, in the study of metals and in their use for specified purposes is also considered, and various methods of measuring such resistance by potential difference and by bridge methods are dealt with. Thermoelectric effects, which form the basis of pyrometry, and which are used in the study of alloy systems, are fully discussed, as well as electrical resistance methods for the measurement of thicknesses, strain and capacity.

X-ray diffraction methods for the study of crystalline structure and lattice formations and for the analysis of thermal diagrams, and the application of X-rays to the detection of flows and cavities in metals by radiographic methods, all of which result from the movement of electrons in a vacuum producing electro-magnetic waves, are dealt with in two instructive chapters. The wave aspect of the nature of electrons or electron diffraction is considered in relation to the examination of metals by means of the electron diffraction camera which is described in detail. Vacuum technique employed in electron diffraction is discussed as well as the interpretation of electron diffraction patterns, and the advantages and limitation of this method of examination, together with recent applications, including the identification of surface films, the examination of electro-deposited metals, and the examination of polished layers, such as occur in bearing surfaces, are reviewed. A chapter of the book is also devoted to types of apparatus termed electron microscopes, and to their applications and limitations in metallurgical investigations.

This volume is concisely written and well indexed, and should prove of considerable value and interest to all scientific metallurgists and to those who wish to obtain a comprehensive knowledge of recently developed methods of physical testing. In addition to the subject matter of the book, details of the process of electrolytic polishing as applied to a number of metals are given in one appendix, while in another appendix are given various X-ray data which are useful for reference, but not suitable for inclusion in the text.

By Bruce Chalmers, D.Sc., Ph.D., F.Inst.P., and A. G. Quarrell, A.R.C.S., Ph.D., F.Inst.P. Published by Messrs. Edward Arnold and Co., 41-43, Maddox Street, London, W. 1. Price, 20s. net.

Transactions of the American Institute of Mining and Metallurgical Engineers

VOL. 143.

INSTITUTE OF METALS DIVISION.

DURING the fifteen years in which there has been a separate Institute of Metals Division volume of the Transactions of the American Institute of Mining and Metallurgical Engineers, there have thus been published nearly 400 technical papers, comprising upwards of 7,000 pages. The present volume, containing 29 papers, is one of the largest of this series, but the quality and scope of these papers are well up to the high standard of previous volumes. The volume contains the annual lecture, which this year was given by Professor George Sachs, on "Some Fundamentals of the Flow and Rupture of Metals." This lecture is an outstanding one, and it held a strong appeal to the theoretical and practical metallurgist.

What is regarded as the first complete contribution on the internal friction in single crystals is given in a paper by T. A. Read, in which he deals with the damping of mechanical vibrations in single crystals of copper and zinc. In this paper he has given a logical and practical explanation of one of the possible causes for internal dissipation of energy. H. L. Burghoff and C. H. Mathewson report the study of the effects of time, temperature, and conditions of loading upon the properties and deformation in tension of single crystals of alpha brass containing about 70% copper and 30% zinc. A serious attempt is made in a paper by W. Kauzmann to interpret creep phenomena from the viewpoint of physics and chemistry. The method of analysis affords a new method of approach towards this interpretation, and merits thoughtful consideration and study. The textures in rolled copper and brass are discussed in a paper by R. M. Brick and M. A. Williamson. Service failures in brass condenser tubes are often due to corrosion, and a paper by J. H. Hollomon and J. Wulff gives an introduction to the subject of inhibition and report the structure of films formed in active corrodants. An interesting paper by D. R. Hull gives some practical observations on inverse segregation made in the course of mill work, and he points out that they mostly tried to confirm the gas theory of Genders.

A paper by M. Cohen and W. P. Kimball deals with the calculation of the composition of the infinitesimal trace of alloy that transfers from the liquid to the solid state at each temperature during the equilibrium solidification of a binary solid solution, and which thereby enables the compositions of the co-existing liquid and solid phases to follow along the liquidus and solidus lines respectively during cooling. A study of the lattice changes that accompany precipitation from the solid solution of silver (20%) in aluminium is reported by C. S. Barrett, A. H. Geisler, and R. F. Mehl. The results of high precision measurements of lattice constants of the silver-rich alpha solid solution in the homogeneous range, and the neighbouring two phase regions of the silver-aluminium system, are given by F. Foote and E. R. Jette. Another paper deals with an investigation, undertaken by F. R. Morral and E. P. Miller, to determine the phases present in hot-dipped heat-treated zinc coatings on steel sheets and wire. Some of the factors that influence creep and recrystallisation of lead are given in a paper by A. A. Smith, Jr.

Altogether, some thirteen papers deal with copper and its alloys, two deal with the light alloys of aluminium and magnesium, five are concerned with physical metallurgy, while the balance deal with miscellaneous non-ferrous alloys, covering a wide and comprehensive field. In addition, the volume is admirably illustrated and produced.

Published by the American Institute of Mining and Metallurgical Engineers, 29, West 39th Street, New York, N.Y., U.S.A. Price, $5·00 net.

THE more important work abstracted in No. 7 issue of "The Nickel Bulletin" includes a review of welding literature on nickel and high nickel alloys, design of pressure vessels, bright nickel plating, influence of cold work on electrical resistance of nickel-copper alloys and details of an American investigation of freezing points of iron and steel.

Copies of the Bulletin may be obtained, free of charge, from The Mond Nickel Company Limited, Grosvenor House, Park Lane, W.1. Individuals should state the name of their firm or indicate the nature of their interest.

* Vol. 1, which deals with optical methods was reviewed in January, 1940, METALLURGIA.

The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen Swells in Canned-Fruit Tinplate Containers*

THE storage of fruit in the " tin can " is a process that has achieved a wide and deserved degree of success. There is, however, an outstanding problem that has so far not been entirely overcome: the formation of so-called hydrogen swells during storage. These " blown " or " domed " cans are caused by the evolution within the can of hydrogen formed by the corrosion of the tinplate by the fruit acids, and are unmarketable. Furthermore, a can that has become domed sometimes suffers actual perforation not long afterwards. Although a great deal of canned fruit is so rapidly consumed that the problem does not arise, there are at least two important directions in which a reduction in the rate of formation of hydrogen swells would be very desirable: (1) In assisting canners to " carry over " packs (a number of cans filled with the same fruit) from one fruit season to the next, when there is a glut, or to ensure against a poor harvest in the next year; (2) in facilitating the export to hot climates of fruits that at present fail too rapidly owing to the increase of the corrosion rate with increase of temperature.

The work described in this paper[1] by T. P. Hoar, T. N. Morris, and W. B. Adam is primarily an investigation of the influence of the sulphur, phosphorus and copper contents of the steel base on the rate of formation of hydrogen swells in a representative selection of British fruits. It is a direct continuation of work by the same investigators recently published as Part I under the same title.[1]

The general plan of the work was as follows: A suitable random sample of 29 cases of tinplate was obtained, and each case was made up into a separate batch of cans under industrial conditions. Two cans from each batch were packed with fruit under standard conditions at the Fruit and Vegetable Preservation Research Station; the packs were stored there at 35° C.,† each can being examined every week for " doming." As soon as this (or in one or two cases, perforation) occurred, the can was removed and emptied. It was analysed for sulphur, phosphorus and copper at the corrosion tests of the steel base were made and finally, the data were reduced by statistical methods.

In the first report, results for black currants, sweet white cherries, gooseberries, loganberries, yellow Pershore plums, raspberries and strawberries in double-lacquered cans were given. It was shown that the rate of formation of hydrogen swells is significantly correlated with the corrosion rate of the steel base in citric acid. For several fruits the rate of swell-formation is lowest when the steel base has a high copper content (up to 0·2%), while for others it is lowest when the phosphorus content is lowest; in general, the authors suggested that the use of high-copper (0·16–0·22%) low-phosphorus (0·03–0·045%) steel should roughly double the expected life of packs of these fruits, on the average.

The corrosion rate and corrosion potential of the steel base of each can, in citric acid, were also measured; correlation of these measurements supported the conclusion that different steels of the type studied have *approximately* similar cathodes, the differences being largely anodic; but the smaller cathodic differences are sometimes of importance. Cathodic efficiency for the reaction $2H^+ + 2E \longrightarrow H_2$ in citric acid appears to be inhibited by increase of sulphur and stimulated by increase of sulphur content. For any steel, the height in millivolts of the corrosion-potential/corrosion-rate point above the average logarithmic curve given by all these points is an indication of the cathode efficiency, and is termed the " cathodic increment."

The results reported in the present paper refer to packs of Czar plums in lacquered cans, and sweet white cherries, gooseberries, yellow Pershore plums, and prunes in plain cans. As with the investigation described in Part I, storage tests of cans have been correlated statistically with chemical analyses and corrosion tests (in citric acid) of the steel base.

As a result of the further work on the subject the general conclusions of Part I are confirmed, and the particular conclusions are supplemented as follows:—

For packs of Czar plums in double lacquered cans and for packs of gooseberries in plain cans, the use of low-phosphorus/high-copper steel base, shown in Part I, to be desirable for six other packs made from unselected material is likely to be somewhat less marked than in the six previously reported cases. For packs of sweet white cherries, Pershore plums and prunes in plain cans, the phosphorus and copper contents of the steel base are immaterial, except in so far as they influence the cathodic increment discussed below. For such packs of cherries, there may be some advantage in a higher sulphur steel base, but sulphur content is immaterial in all the other cases here reported.

For the packs of sweet white cherries, gooseberries and prunes here studied, the rate of formation of hydrogen swells was significantly smaller for cans made from steel bases showing lower cathodic increments; thus it is probable that such steel base is in general desirable for such packs.

For the packs of raspberries, strawberries (Part I) and Czar plums (Part II) in double-lacquered cans, the corrosion rate of the can steel base in fruit juice gave a poorer correlation with the time of formation of hydrogen swell than did the corrosion rate in citric acid, while the corrosion rate in boiling dilute hydrochloric acid (11% HCl by weight) gave the best correlation of all. Reasons for these results are advanced, and suggestions for rational corrosion tests of tinplate based on them are made.

Differences between lacquered- and plain-can packs are discussed. It is suggested that steel base composition is important for plain-can packs mainly in so far as it influences the cathodic increment.

The authors conclude with a tabular summary, which is reproduced in the accompanying table, setting forth the main conclusions of Parts I and II of this research with regard to the most suitable tinplate steel base for the various fruit packs investigated. It must be emphasised that these recommendations refer *only* to pack-rolled steel base as normally manufactured in this country prior to the present war. Where a recommendation is bracketed, it is of subsidiary importance.

RECOMMENDED TINPLATE STEEL BASE FOR VARIOUS PACKS.
HS: High sulphur (phosphorus normal).
L Δ E: Cathodic increment as negative as possible.
LP/HCu: Low phosphorus/high copper.

Fruit.	Lacquered Cans.	Plain Cans.
Black currants	LP/HCu	—
Sweet white cherries	L Δ E	L Δ E; (HS)
Gooseberries	LP/HCu: L Δ E	L Δ E: (LP/HCu)
Loganberries	LP/HCu	—
Czar plums	LP/HCu	—
Pershore plums	LP/HCu	Immaterial
Prunes	—	L Δ E
Raspberries	LP/HCu	—
Strawberries	LP/HCu	—

* T. P. Hoar, T. N. Morris, and W. B. Adam. Part II. Iron and Steel Institute, 1941. Advance copy.

† This temperature imitates the tropical conditions under which cans fail rapidly, and provides a legitimate degree of acceleration of the tests, as compared with the rate of formation of hydrogen swells at ordinary " temperate " temperatures.

1 T. P. Hoar, T. N. Morris, and W. B. Adam. "The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen Swells in Canned Fruit Tinplate Containers." Part I. *Jour. of the Iron and Steel Institute*, 1939, vol. ii, p. 55.